University of Alberta

Ft.McKay Community Exposure Study: Assessment of Particulate Matter (PM_{10}) Levels

by

Bettina Mueller ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

Environmental Engineering

Department of Civil and Environmental Engineering

Edmonton, Alberta

Spring 2001

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The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled **Ft.McKay Community Exposure Study: Assessment of Particulate Matter (PM_{10}) Levels** in partial fulfillment of the requirements for the degree of **Masters of Science** in **Environmental Engineering.**

W Kindzierski

Dr. Warren Kindzierski

S. Guigard

Dr. Selma Guigard

John Feddes

Dr. John Feddes

April 2, 2001

Abstract

Ft. McKay is located in close proximity to oil sands activities in Northern Alberta. Air sampling of PM_{10} outdoors and at 30 homes was undertaken during fall 1999, and winter 2000.

Mean ambient PM_{10} levels were low during the fall ($6.2\mu g/m^3$) and winter ($16\mu g/m^3$). None of the ambient measurements exceeded proposed or existing PM_{10} standards. Mean Indoor PM_{10} concentrations were high during the fall ($83.4\mu g/m^3$) and winter ($48.4\mu g/m^3$). Indoor/outdoor ratios (fall:19.5, winter:5.5) suggest that significant indoor sources for PM_{10} were present. Ambient measurements were not a good predictor for indoor concentrations. Winter mean ambient PM_{10} levels were higher than fall; indoor mean PM_{10} levels were higher during the fall than winter. PM_{10} measurements from a central monitoring site were representative for PM_{10} levels across Ft. McKay. Air exchange measurements obtained during the fall sampling period ranged from 0.15 to 0.73 ACH.

Acknowledgements

This study was made possible with the generous financial support of the Ft. McKay Industrial Relations Corporation (IRC), Syncrude Canada Ltd., Suncor Energy Ltd., Mobil Oil Ltd., and the Northern Lights Regional Health Authority/Alberta Health.

The contributions of the residents of Ft. McKay, without whose participation this study would not have been possible, are gratefully acknowledged.

I would like to thank Dr. Warren B. Kindzierski, Department of Civil and Environmental Engineering, University of Alberta, for providing me with the opportunity to work on this project. Numerous contributions were made by other staff and students from the Environmental Engineering Department. I would like to thank Kevin McCullum for readily answering questions and Gwen Mendoza for outstanding administrative support.

Special thanks to Madeline Delisle, IRC, whose creative people finding skills were essential to the success of this study. Her tireless efforts, great sense of humor and introduction to the art of Suki Yamoo were greatly appreciated.

Thank you to Angela Wharmby, ARC, Vegreville, and George Braybrook, University of Alberta, for excellent customer service at their laboratories.

To Vincent K. Waldon – the greatest engineer walking this planet- a special thank you for sharing his intimate knowledge of the Canadian Tire Automotive Department, suggestions for the MiniVol incubator, and review of the manuscript.

I would like to thank my friends SaiYah Joo-Hackett, Lynne Langager, Isolde Schmid, Suzanne Belanger, and Rhonda Breitkreutz, for providing encouragement to enter the program, nutritional aid, childcare, and suggestions for dealing with Canadian university culture.

Thank you to Anneliese Mueller for coming to the rescue when the candle started burning at both ends.

Last but not least, a thank you to the three most important men in my life, Jeff Foster, Vincent, and Joshua Foster-Mueller, whose relentless support, understanding, and commitment to myself and my studies enabled me to continue my career while enjoying the privilege of having them as family.

While many people contributed to this work, errors and omissions are to be considered my own.

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List of Abbreviation and Symbols

ACH	Air changes per hour
AQS	Air Quality Standard
ARC	Alberta Research Council
$CaCO_3$	Calcium Carbonate
CAT	Capillary Absorption Tube
D_{ae}	Aerodynamic diameter (diameter of a spherical particle with equal settling velocity but a density of 1g/cm^3)
ETS	Environmental Tobacco Smoke
H^+	Hydrogen Ion
H_2O_2	Hydrogen Peroxide
H_2S	Hydrogen Sulfide
h_υ	Solar radiation
I/O	Indoor/Outdoor
MDL	Method Detection Limit
NAAQS	National Ambient Air Quality Standard
NaCl	Sodium Chloride
NH_3	Ammonia
NH_4^+	Ammonium
NO_3^-	Nitrate
NO_x	Nitrous Oxides
O_3	Ozone
OH	Hydroxyl radical
PCMH	Perfluoromethylcyclohexane
PFT	Perfluorotracer
PM	Particulate Matter
PTEAM	Particle Total Exposure Assessment Methodology
QA/QC	Quality Assurance/Quality Control

QAO	Quality Assurance Objective
R.H.	Relative Humidity
RSD	Relative Standard Deviation
SO_2	Sulphur Dioxide
SO_4^{2-}	Sulfate
SO_x	Sulphur Oxides
TEAM	Total Exposure Assessment Methodology
TSP	Total Suspended Particulate
U.S. EPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WBEA	Wood Buffalo Environmental Association

1 Introduction

1.1 Background

The community of Ft McKay is located in northern Alberta, 55 km north of Ft. McMurray. Its close proximity to oil sand industries has raised concerns among the residents regarding the air quality in the region. In response to those concerns an indoor/outdoor air quality study of selected pollutants- particulate matter, sulfur dioxide and volatile organic compounds – was performed. The focus of this work was the assessment of current particulate matter levels in the community of Ft. McKay. Others reported on the results for the other two compounds.

Ambient Particulate Matter (PM) consists of particles of varying size and chemical composition. The potential health effects of PM have led regulatory bodies to implement standards. Particulate matter is generally classified as TSP, total suspended particulate, PM_{10} – that is particles of an aerodynamic diameter of 10 μm and smaller and $PM_{2.5}$, which is the size fraction of 2.5 μm and smaller.

The Athabasca region in northern Alberta contains significant oil sand deposits. Oil sands development began in the 1960s, with production of synthetic crude oil starting in the seventies. Production increased steadily, reaching approximately 300,000 barrels/day in 1998. An increase in production to about 400,000 barrels /day from already approved increases at Syncrude Canada Ltd. and Suncor Energy is anticipated by the year 2002. It is projected that overall production rates will increase to 880,000 barrels by 2008 (Athabasca Oil Sands Trust, 1999; Kindzierski, 1999; Suncor Energy, 1999; Syncrude

Canada Ltd., 1999). This increase represents a doubling in production rate. With an increase in production, an increase in atmospheric emissions of air pollutants can be expected. This increase in oil production will lead to an increase in PM_{10} concentrations. Kindzierski (1998) estimated that a total of 15 t/d of PM_{10} will be emitted from all approved, proposed, and disclosed oil sands plant sources. Pre-1998 emission levels for PM_{10} were estimated to be 6.1 t/d.

Ambient levels of PM_{10} are measured at the Wood Buffalo Environmental Association (WBEA) Ft. McKay monitoring station, which is located approximately 1 km north of Ft. McKay. However, it was not clear if ambient measurements made at the monitoring station were a good representation of outdoor PM_{10} levels, and PM_{10} levels inside residences of Ft. McKay. Previous studies found that ambient measurements were not a good representation of indoor PM_{10} levels (Anon, 2000; Pellizari *et al.*, 1992).

1.2 Description of Study Area

The predominantly First Nations/Metis community of Ft. McKay is located in northeastern Alberta, within the municipality of Wood Buffalo, Canada, approximately 500 km northeast of Edmonton. The population of Ft. McKay was 365 according to the 1996 Canada Census. The hamlet is located directly adjacent to the Athabasca River on the east, the McKay River to the south and Ells River to the north. The community is accessible from Ft. McMurray via paved Highway 63, which ends at this point (Figure 1.1).

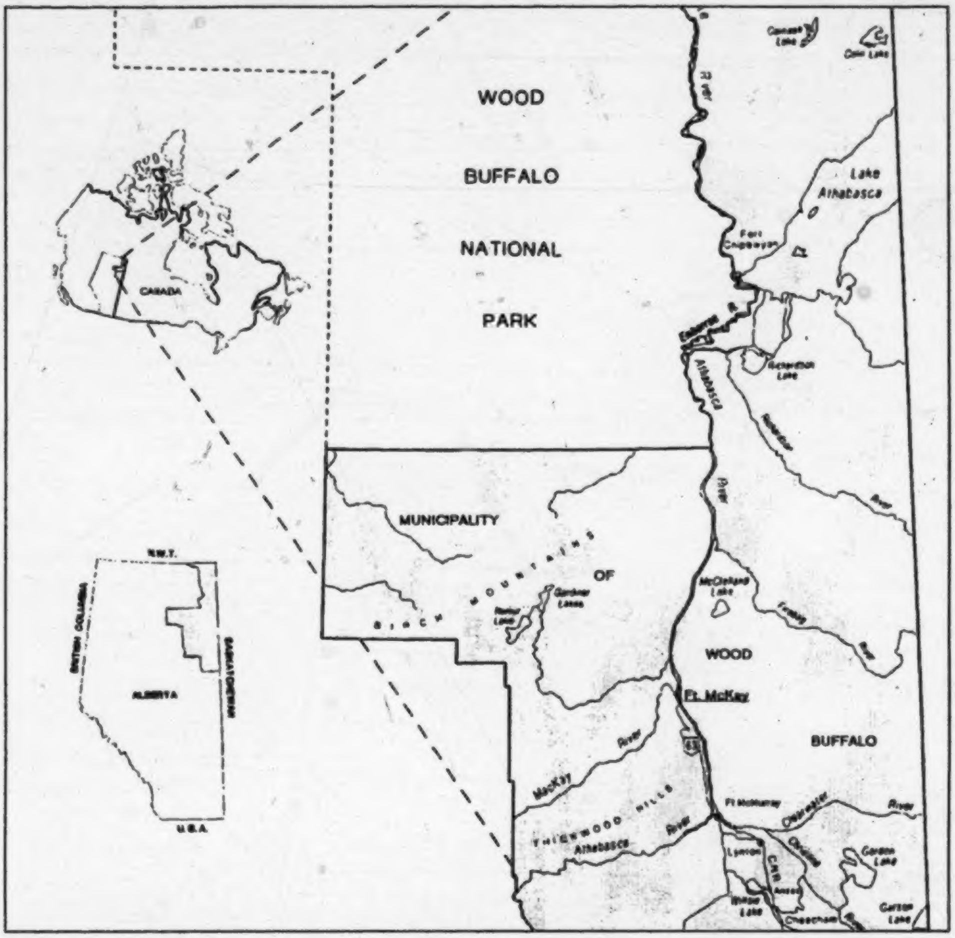

Figure 1.1: Location of Ft. McKay within the Municipality of Wood Buffalo, Alberta and Canada

Ft. McKay is virtually surrounded by existing and proposed oil sands development (Figure 1.2). Approximately 15 km south of Ft. McKay is the oil sands extraction and upgrading facility of Syncrude Canada, with the Mildred Lake Mine extending north and towards Ft. McKay. Twenty-five km south on the west and east side of the Athabasca River is Suncor Energy's oil sands extraction and upgrading facility and the Steepbank, Millenium and Lease 16/17 Mines. Further, Syncrude has construction underway at

Aurora, the North Mine Area and Upgrader Debottleneck, while Suncor Energy has Project Millenium under construction. The proposed Muskeg River Mine and extraction plant owned by Shell Canada Ltd. will be located on the eastern banks of the Athabasca river approximately 10 km north of the Ft. McKay town site. Other oil sands related projects are proposed by Mobil Oil, as well as construction of pipelines to facilitate bitumen transport to the Edmonton area.

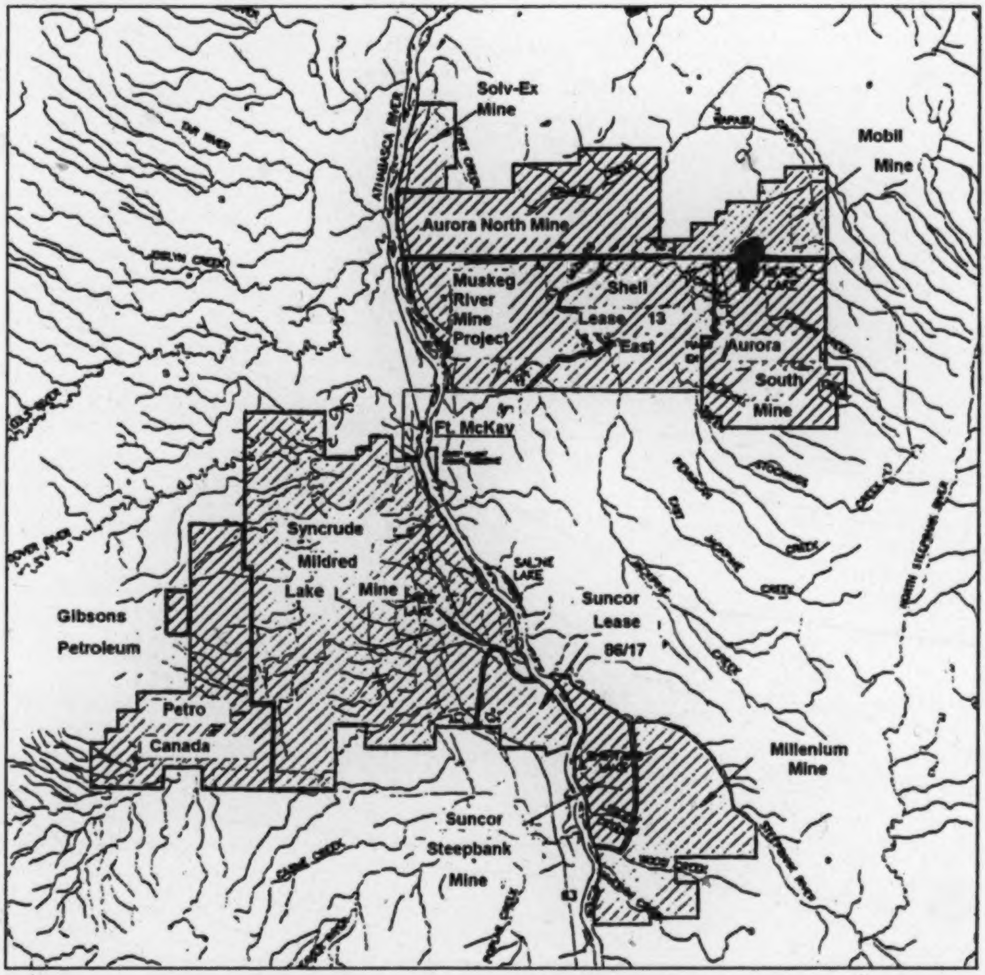

Figure 1.2: Current and proposed oil sands developments in North-Eastern Alberta

1.3 Study Objective

The objective of this study was to:

- collect baseline particulate matter (PM_{10}) data at current production levels of the oil sands industry in the community of Ft. McKay in a manner that facilitates direct comparison with future PM_{10} data collection,
- assess potential exposure in the population to PM_{10},
- estimate the seasonal variation of PM_{10} levels in the study area,
- determine if ambient PM_{10} measurements obtained at the WBEA Ft. McKay meteorological station are a good representation of outdoor PM_{10} levels in Ft. McKay.

1.4 Particulate Matter

Particulate matter consists of a mixture of particles of varying size and chemical composition. Particles of less than 10 μm aerodynamic diameter can be inhaled (PM_{10}). The fraction of particles that are less than 2.5 μm can be retained in the airways and lungs (CEPA/FPAC, 1998; Environment Canada *et al.*, 2000; Sloss, 1998; Smith *et al.*, 1998; U.S.EPA, 1996).

Particulate matter originates from a variety of sources– natural and anthropogenic. Sources can be found indoors and outdoors. Ambient sources of PM_{10} are windblown soil, sea salt, forest fires and industrial activities. $PM_{2.5}$ particles are formed from gases released to the atmosphere by combustion processes such as power plants, motor vehicles and household heating. Sources of indoor PM_{10} and $PM_{2.5}$ are soils that have been tracked in, and are resuspended through people movement, animal dander, cooking activity, cleaners, building materials and tobacco smoke (CEPA/FPAC, 1998).

1.5 Overview of Study

Regulatory bodies have focussed on outdoor environments for regulation, thus most research has targeted outdoor air quality and its relation to health outcomes. In order to measure exposure, fixed station outdoor monitors were predominantly used to provide measurements of selected pollutants for a given geographical area. Studies indicate however that people spend up to 90% of their time indoors (Chapin, 1974; Health Canada, 1989; Szalai, 1972). Therefore, to measure human exposure it is instrumental to assess pollutant levels indoors, as the building structure can modify the concentration of ambient pollutants. Building materials, consumer products, appliances and human activities can contribute to pollutant levels in the indoor environment (Health Canada, 1989; U.S. EPA, 1991).

The primary goal of this study was to assess the ambient and indoor PM_{10} levels in homes of residents of Ft. McKay at current levels of activity of the oil sands industry. Probability sampling methods were utilized to allow for a direct comparison of the collected data with future studies. Sampling locations were randomly selected to avoid bias of the homes sampled. The population was stratified according to housing type (manufactured home and house), as this would provide a more homogenous sample, and ensure geographical representation since most manufactured homes are clustered on the west side of Ft. McKay.

The recruitment process for establishing which residents to sample was initiated through a general information letter sent to all community members of Ft. McKay. This was followed by a door-to-door campaign in which all randomly selected households were contacted, the sampling procedure was explained in detail, and written consent to participate in the study was attempted. If consent was obtained a sampling appointment was scheduled. To aid the recruitment process, a Recruitment Status Form, Recruit Consent Form, and Participant Information Sheet were developed (Appendix A). Further, a training seminar was conducted with field staff to familiarize them with the study, recruitment procedures, and questionnaires. Questionnaires were developed to identify potential local sources of PM that may interfere with the interpretation of the results (Appendix B).

To account for seasonal variation, sampling was conducted during two time periods: September and October 1999 and January and February 2000.

2 Literature Review

2.1 Air Pollution

Air Pollution can be defined as " the presence in the outdoor atmosphere of one or more contaminants in quantities and duration that can injure human, plant, or animal life, or property, or which unreasonably interferes with the enjoyment of life or the conduct of business" (Altwicker *et al.*, 1999). This definition includes the quantity of the pollutant and the duration of occurrence, which is an important concept as pollutants occurring in low concentrations or for only brief periods of time may be insignificant regarding ambient air quality concerns.

Air pollution transport and dispersion are influenced by precipitation, wind speed and direction, the solar cycle, the temperature structure of the atmosphere, turbulence, and changes in these elements due to local topography (Altwicker *et al.*, 1999).

Air pollution is not a recent phenomenon. In 1273, the first smoke-abatement act was issued for London and other English cities, followed by a royal proclamation in 1306 forbidding the burning of coal during sessions of Parliament. Violation of the ordinance was punished with death (Bibbero *et al.*, 1974). However, by the 17th century, the edict of 1306 had been forgotten; continual exacerbation of the problem resulted in a disaster in 1952 with nearly 4,000 people dying within one week of effects attributed to "smog", and another 8,000 over the next three months. Great Britain's Clean Air Act was implemented in 1956 in order to prevent a recurrence of the London "episode" (Bibbero *et al.*, 1974).

Air quality standards have generally focused on ambient air or occupational exposure. Not until recently has more attention been directed to the indoor environment. It became apparent that non-industrial indoor environments can contribute significantly to human exposure to air pollutants. Recognizing this, the World Health Organization recommended in 1979 that health authorities draw up guidelines for indoor concentrations of contaminants to protect the health of occupants. Health Canada published guidelines for residential indoor air quality in 1987 (Health Canada, 1989). Therefore, it has become evident that in order to accurately assess exposure of humans to air pollution, sampling of indoor air is instrumental.

2.2 Exposure

The U.S. EPA defines exposure as the contact of a chemical with the outer boundary of the body (U.S. EPA, 1992). The outer boundary consists of skin, and the openings into the body such as the mouth, nostrils, and punctures into the skin. Others have defined exposure more generally as the contact between a target (i.e. human) and a chemical, physical, or biological agent in an environmental carrier medium (Georgopolous, 1994; NAS *et al.*, 1991; Ott, 1982; Zartarian *et al.*, 1997).

Exposure over a period of time can be represented by a time dependent profile of the exposure concentration (U.S. EPA, 1992).

$$E = \int_{t1}^{t2} C(t)dt \qquad \textbf{Equation 1}$$

E = magnitude of exposure
$C(t)$ = exposure concentration as a function of time
t = time
t_2-t_1 = exposure duration

The area under a concentration (C(t)) versus time (t)) curve represents the magnitude of exposure in concentration – time units.

Delineation of exposure for a given individual exposed to multiple pollutants, and spending time in different microenvironments can be described by (NAS *et al.*, 1991):

$$\Delta E_{i,j,k} = \sum_{i=1}^{I} C_{i,j} * \Delta t_{j,k}$$ **Equation 2**

$\Delta E_{i,j,k}$ = exposure of individual "k" to a pollutant "i" during time interval "Δt" as a result of activities in micro-environment "j"

$C_{i,j}$ = average concentration of pollutant "i" to which individual "k" is exposed to in microenvironment "j" during time interval "Δt". Considered constant for that location during time interval "$\Delta t_{j,k}$"

$\Delta t_{j,k}$ = time spent by individual "k" in microenvironment "j"

Thus, personal exposure to a contaminant present in a microenvironment will only occur if the individual is present in the microenvironment.

2.2.1 Exposure Assessment

One of the essential steps in risk assessment and management is the assessment of exposure to a contaminant. Exposure assessment requires the identification of conditions under which humans will be exposed to a substance. It is a process that seeks to identify the source/media of exposure (i.e. air, water, food, and soil), transport mechanisms, entry routes into the body (ingestion, inhalation, dermal), intensity and frequency of contact, and spatial and temporal concentration patterns of contaminants.

This information can be obtained through several different processes of which some are more accurate, and usually more expensive, such as personal monitoring and biological monitoring. Figure 2.1 provides an overview of possible approaches to assess exposure to air contaminants.

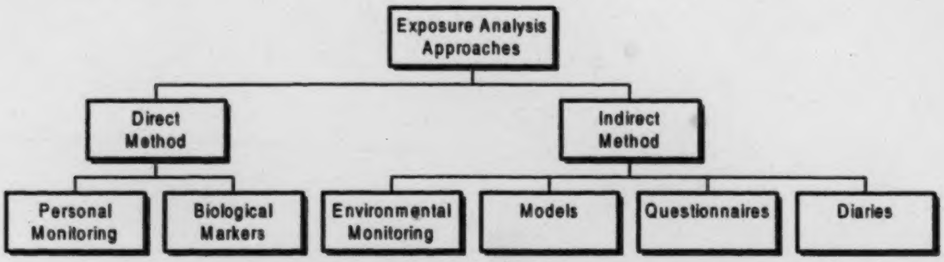

Figure 2.1: Approaches to exposure measurement.
(adapted from NAS *et al.*, 1991)

Personal monitoring and biological monitoring can be categorized as direct methods; they involve measuring the concentration of pollutants in the air breathed, and the food and water ingested (Ott, 1985). Biological monitoring involves the assessment of bio-markers, which are cellular, molecular, or biochemical measures taken from media such as human tissue and fluids, and are indicative of the presence of pollutants (NAS *et al.*, 1991). Micro-environmental monitoring can be classified as an indirect approach to exposure assessment which seeks to combine time activity information with the expected pollutant concentration in a particular location (Ott, 1985).

For predictions of exposure, modeling can be used. Mathematical models attempt to describe interactions between chemical, physical or biological systems using a system of equations. The goal is to simplify a complex problem to a manageable one (NAS *et al.*, 1991). Models can aid in the understanding of important factors affecting fate and behaviour of chemicals in environmental systems. It is important, however, to understand the assumptions and limitations of the model and recognize that results may not be accurate.

Questionnaires and time-activity diaries are tools utilized to obtain information regarding the physical properties of the microenvironment, potential sources of the pollutant of interest and activity patterns.

The indirect approach gathers information from all the above sources to construct an exposure profile (NAS *et al.*, 1991). An individual's personal habits can have a strong influence on human exposure, a fact that complicates the process of assessing human exposure to a contaminant.

2.2.2 Significance of Indoor Air in Exposure Assessment

In order to evaluate the exposure of humans to a contaminant, it is essential to examine the environment where humans spend most of their time. Studies indicate that North Americans spend up to 90% of their time indoors (Chapin, 1974; Health Canada, 1989; Szalai, 1972). Despite this, the general public perceives the risk of outdoor pollution as being substantially higher than from indoor pollution (LHEA, 1997 cited in (Jones, 1999)). This is most likely due to the fact that indoor pollution is often invisible, whereas obvious photochemical and particulate substances often characterize outdoor pollution.

A trend to tighter building construction since the 1970 oil crisis, in order to conserve fuels, led to an increased recirculation of indoor air. Houses with ventilation rates of 0.2 –0.3 air exchanges per hour are now widespread. In older residences ventilation rates of 1 air exchange per hour and higher is common (Jones, 1999). Additionally, an increased presence of synthetic chemicals used in building and insulating materials, furnishings, consumer products and hobby materials can lead to an accumulation of pollutants indoors. The use of heating systems, which, if not properly installed or designed, can release combustion by-products, can contribute to indoor air pollutant concentrations (Health Canada, 1989; U.S. EPA, 1991).

The concentration of an indoor pollutant depends on the relationship between the volume of air contained in the building, the rate of production or release of the pollutant from the air via reaction or settling, the rate of air exchange with the ambient air, and the outdoor pollutant concentration (Abt *et al.*, 2000; Maroni *et al.*, 1995).

The findings of several studies indicate that indoor concentrations of pollutants can be substantially higher than outdoor concentrations (Abt *et al.*, 2000; Anon, 2000; Ozkaynak *et al.*, 1996; Spengler, 1985). Studies indicate a strong influence of indoor PM concentrations on personal PM exposure, whereas personal PM concentrations are only weakly correlated with ambient PM concentrations (Ozkaynak *et al.*, 1996; Spengler, 1985).

2.2.3 Personal Air

A limited number of studies have measured personal exposure to particulate matter (Ozkaynak *et al.*, 1996; Spengler, 1985; Wallace, 1996). The authors observed that in non-smoking households mean levels of PM_{10}, $PM_{2.5}$ and $PM_{3.5}$ in personal air were elevated compared to PM levels in indoor air. Increases in personal air concentrations ranged from 1.5-2.5 times higher than indoor air concentrations. The difference in concentration was attributed to the "personal cloud" (Wallace, 1996). The Particle Total Exposure Assessment Methodology (PTEAM) study results indicated that it consists mainly of the same aerosols as found indoors and outdoors – 14 of the 15 elements analyzed were elevated in the personal air. Elemental composition would have been different if the cloud consisted mostly of fibers and skin flakes from the human body (Pellizari *et al.*, 1992).

The source of the difference between the personal exposures and indoor concentrations has not been determined. It is likely due to resuspension and generation of particles during personal activities (Clayton *et al.*, 1993; Pellizari *et al.*, 1992; Wallace, 1996). The data of the PTEAM study exhibit a definite diurnal trend with personal exposure being elevated during the day but not during rest time at night.

Correlation between ambient concentrations and personal concentrations is generally poor. Improved correlation can be observed between indoor concentrations and personal concentrations in the absence of important micro-environmental sources such as smoking (Wallace, 1996). Additionally, cross-sectional analysis of data may influence the observed correlation between personal exposures and outdoor concentrations; possibly due to the inter-personal variability masking intra-personal correlation (Janssen *et al.*, 1998).

2.3 Particulate Matter

Ambient particulate matter consists of a mixture of particles of varying size and chemical composition. Particles with an aerodynamic diameter (D_{ae}) less than 10 μm can be inhaled. The fraction of particles that are less than 2.5 μm can be retained in the airways and lungs. Therefore, it is the fine fraction that is of greatest health concern.

Particulate matter originates from a variety of sources including natural and anthropogenic. Particles smaller than 2.5 μm are categorized as fine particles, particles larger than 2.5 µm to 10 µm are categorized as coarse particles. Fine particles result predominantly from fuel combustion as well as from formation in the atmosphere from gases such as sulfur dioxide, nitrogen oxides, and volatile organic compounds. Coarse particles are generally emitted from sources such as windblown dust and industrial crushing and grinding operations. (Altwicker *et al.*, 1999; Beckett *et al.*, 1998; CEPA/FPAC, 1998; Chow, 1995; Chow *et al.*, 1998; Environment Canada *et al.*, 2000; Gamble *et al.*, 1996; McClellan *et al.*, 1997; OME *et al.*, 1999; Sloss, 1998; Smith *et al.*, 1998; U.S.EPA, 1996; Wallace, 1996)

2.3.1 Characteristics of Particulate Matter

Particulate matter exhibits a range of morphological, chemical, physical, and thermodynamic properties. It can exist as a solid, liquid or a solid core surrounded by liquid, which can contain inorganic ions, elements, elemental carbon, organic, and crustal compounds. The size of PM ranges from a few nanometers to 100 µm with combustion generated particles and particles produced in secondary formation processes occupying the smaller size fraction (<2 µm) and windblown dust, pollens, and cement dust representing the larger size fraction. The composition and behaviour of particles is directly related to surrounding gases (Altwicker *et al.*, 1999; Beckett *et al.*, 1998; CEPA/FPAC, 1998; Chow, 1995; Chow *et al.*, 1998; Environment Canada *et al.*, 2000; Gamble *et al.*, 1996; McClellan *et al.*, 1997; OME *et al.*, 1999; Sloss, 1998; Smith *et al.*, 1998; U.S.EPA, 1996; Wallace, 1996).

PM can be categorized as primary and secondary particles: primary particles are directly emitted into the atmosphere. The concentration of these particles depends on the emission rate, transport, dispersion and removal rate in the atmosphere. Secondary particles form from condensable vapours formed by chemical reactions involving gas-phase precursors, or through chemical reactions of free, adsorbed or dissolved gases, hence resulting in formation of new particles, or addition of particulate matter to already existing particles (U.S.EPA, 1996).

Figure 2.2 gives a simplified overview of the atmospheric chemical cycle that leads to the formation of secondary particulate matter.

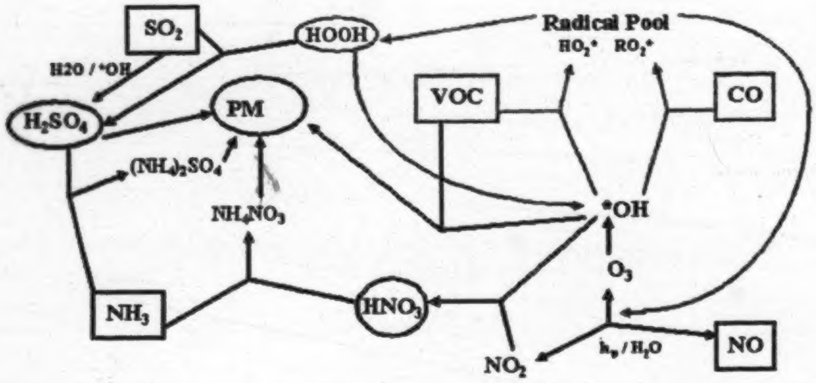

Figure 2.2: Formation of secondary PM – simplified
(adapted from Environment Canada, 1998).

Sources of primary emissions are given in square boxes, and sinks or points where chemicals are removed from the atmosphere are given in circles. Intermediate species are connected by arrows that can represent many chemical reactions. One to one reactivity is not implied. The formation depends on the presence of other gas species such as ozone (O_3), hydroxyl radical (OH), Hydrogen Peroxide (H_2O_2); atmospheric conditions such as solar radiation (h_υ) and relative humidity, interactions with pre-existing particles and precursors within cloud or fog droplets (CEPA/FPAC, 1998; Environment Canada, 1998; U.S.EPA, 1996).

This very complex process makes it difficult to relate ambient concentrations of secondary species to sources of precursor emissions.

2.3.2 Composition of Particulate matter

Aside from size, particulate matter can have distinctively different compositions. While the coarse fraction is dominated by oxides of crustal elements (Si, Al, Ti, Fe), NaCl, $CaCO_3$, and by organic matter such as pollen and molds; fine particulate matter consists of Sulfate (SO_4^{2-}), Nitrate (NO_3^-), Ammonium (NH_4^+), Hydrogen Ion (H^+), elemental carbon, organic compounds (e.g. poly-aromatic hydrocarbons), metals (e.g. Pb, Cd, V, Ni, Cu, Zn, Mn, Fe) and particle-bound water (CEPA/FPAC, 1998; Chow, 1995; U.S.EPA, 1996).

Further, coarse particles are largely insoluble and non-hygroscopic, whereas fine particles are predominantly soluble, hygroscopic and deliquescent (Grant, 1997).

2.3.3 Definition of Size Distribution

Different approaches have been taken to define the size distribution of particulate matter: modality, place of deposition in the lungs, and one derived from size-selective sampling.

Morawska (1999) and Tucker (1998) suggested a bi-modal distribution of PM in ambient air, with a minimum between 1-3 µm aerodynamic diameter (Morawska *et al.*, 1999; Tucker, 1998). The aerodynamic diameter (D_{ae}) is the diameter of a spherical particle with equal settling velocity but a density of $1 g/cm^3$. Thus particles with the same size and shape but different densities will have a different aerodynamic diameter. Figure 2.3 shows the bi-modal size distribution of particulate matter and fractions used for size-selective sampling.

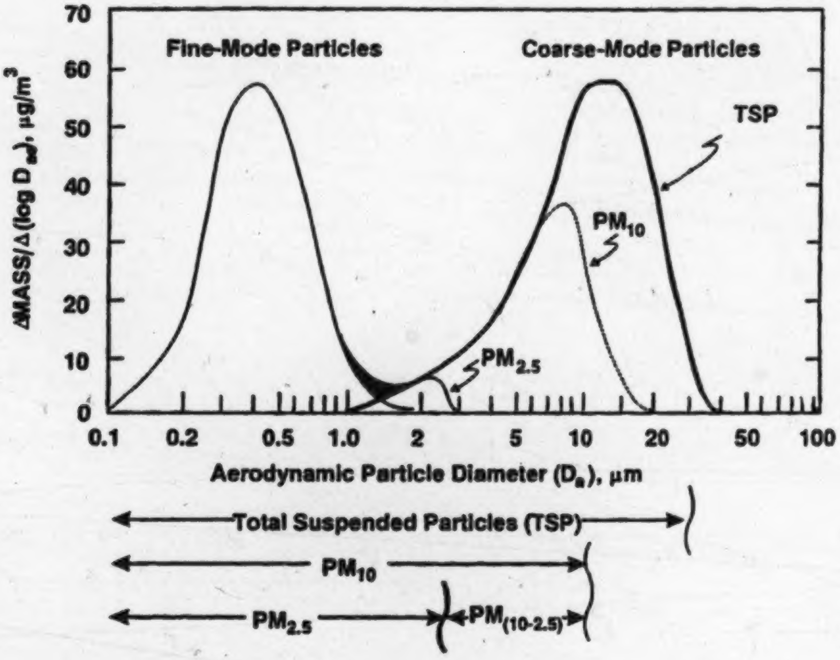

Figure 2.3: Bi-modal size distribution of particulate matter, showing the fractions collected by size-selective samplers
(adapted from Tucker, 1998; U.S. EPA, 1996).

The distribution of particles larger than the minimum is generally referred to as coarse particles; particles smaller than the minimum as fine particles. Whitby and Sverdrup (1980) suggested a tri-modal size distribution:

- nuclei mode also referred to as Aitken Nuclei: particles smaller than 0.1 μm. This mode is only observed in clean remote areas. Nuclei mode particles grow rapidly into accumulation mode particles,
- accumulation mode: particles from 0.1 to 1-2 μm. These are secondary PM formed from chemical reactions in the atmosphere,
- coarse particle mode: particles larger than 1-2 μm, generally primary particles (Whitby *et al.*, 1980).

The second approach classifies particles into inhalable, thoracic, and respirable particles relating to their entrance location into the respiratory system. Inhalable particles generally reach the extra thoracic region, thoracic particles reach the lung airways and the alveoli, and respirable particles reach the alveoli (Owen *et al.*, 1992).

The third approach derives its relevance form size-selective sampling. Size selective sampling is the collection of particles within a specified aerodynamic size range, generally defined by the 50% cut-point, which is the D_{ae} at which 50% of the suspended particles are able to penetrate through the inlet to the filter (Chow, 1995). It is this classification that is used as an indicator for the setting of PM standards, as it relates directly to the inhalation characteristics of the respiratory tract, which does not separate particles with a sharp cut. PM_{10} is defined as having a 50% cut-point at 10 μm D_{ae}. Thus, PM samplers collect a decreasing fraction of particles as the D_{ae} increases above 10 μm, and an increasing fraction of particles as the D_{ae} decreases below 10 μm (see Figure 2.3). This simulates the behaviour of the respiratory tract, where 50% of PM_{10} are able to penetrate beyond the larynx (U.S.EPA, 1996).

2.4 Particulate Matter Standards

For the purpose of setting of standards, PM is currently categorized into three size ranges: Total Suspended Particulate (TSP), PM_{10}, and $PM_{2.5}$. Typically TSP has an aerodynamic diameter smaller than 100 μm, PM_{10} an aerodynamic diameter smaller than 10 μm, and $PM_{2.5}$ an aerodynamic diameter smaller than 2.5 μm.

While Alberta's environmental standards currently regulate TSP, most regulatory bodies now focus on PM_{10}, and most recently on $PM_{2.5}$ as it has become evident that fine particulate matter is generally a better predictor of health effects than PM_{10} (Krzyzanowski *et al.*, 1997).

Table 2-1 provides a selection of current and proposed PM standards. The variety of standards observed in different jurisdictions is indicative of the lack of complete understanding of the pollutant particulate matter and its effects on human health. While there is now a general consensus that particulate matter can be detrimental to human health, there is still uncertainty about existence of a threshold value, the adequate metric to use for regulatory purposes, and the mechanism, which could explain the observed health effects of particulate pollution (U.S.EPA, 1996).

Table 2-1: Overview of selected current and proposed particulate matter standards.

JURISDICTION	REGULATION
Canada (CCME, 1999)	No current standard Proposed by 2010: PM$_{2.5}$ of 30 μg/m^3 as a 24-hour average [1]
USA (U.S.EPA, 1996)	PM$_{10}$ 50 μg/m^3 annual mean [2] 150 μg/m^{3}as a 24-hour average [3] PM$_{2.5}$ 15 μg/m^{3}annual mean[2] 65 μg/m^3 as a 24-hour average[4]
Europe (EU) (Olsthoorn *et al.*, 1999)	No current standard Proposed: PM$_{10}$ to be met by 2005 50 μg/m^3 as a 24-hour average[5] 30 μg/m^3 annual average by 2010: 50 μg/m^{3}as a 24-hour average[6] 20 μg/m^3 as an annual average
World Health Organization (Krzyzanowski *et al.*, 1997)	No Level established[7]
Alberta, Canada (Alberta Environment, 1998)	TSP 100 μg/m^{3}as 24-hour average 60 μg/m^3 as annual geometric mean
California, USA (OME *et al.*, 1999)	PM$_{10}$ 50 μg/m^{3}as 24-hour average 30 μg/m^3 as annual average
United Kingdom (OME *et al.*, 1999)	PM$_{10}$ 50 μg/m^{3}as 24-hour average
Sweden (OME *et al.*, 1999)	PM$_{10}$ 100 μg/m^3 as 24-hour average

[1] based on the 3 year consecutive average of the annual 98th percentile ambient measurement

[2] based on the 3 year average of the annual arithmetic mean concentration

[3] based on the 3 year average of the 99th percentile of 24-hour concentrations

[4] based on the 3 year average of the 98th percentile of 24-hour concentrations

[5] 98th percentile of 24-hour averages not to be exceeded more than 25 times a year

[6] not to be exceeded more than seven times a year

[7] epidemiological data did not facilitate the establishment of a level below which no effects would be expected. Exposure-effect information was provided as guidance to risk managers.

2.5 Indoor/Outdoor Sources of Particulate Matter

Particulate matter is a broad class of chemically and physically diverse substances that exist as discrete particles over a range of particle sizes. Sources for particulate matter exist both indoors and outdoors.

2.5.1 Outdoor Sources

Ambient particulate matter originates from natural sources such as soil, sea spray, dust, fires, and plant pollens, as well as from anthropogenic sources including agricultural practices, forestry, combustion, transportation, and industries (McClellan *et al.*, 1997).

As previously discussed, particles may be emitted directly (primary particles), or formed in the atmosphere by transformation of emissions such as nitrogen oxides, sulfur oxides, and VOC's (secondary particles). Primary and secondary fine particles can have lifetimes of weeks in the atmosphere and are able to travel hundreds to thousands of kilometers. They tend to be uniformly distributed over urban and regional areas and thus are difficult to track back to their sources. Coarse particles have lifetimes ranging from minutes to hours and travel short distances (<10km) (Grant, 1997). Hence distribution of coarse particles is less even, leading to more localized effects.

Table 2-2 gives an overview of sources of fine ($PM_{2.5}$) and coarse (PM_{10}) particulate matter.

In the United States the largest source of emission of primary PM are fugitive sources followed by combustion sources. At eastern U.S. sites stationary combustion and fugitive dust are major contributors to outdoor PM, while at western sites fugitive dust, motor vehicles, and wood smoke are major contributors to outdoor PM. Nitrates and organic carbon are the major secondary components of PM in the West, while sulfate and organic carbon are the major secondary components in the East (U.S.EPA, 1996).

Table 2-2 Natural and anthropogenic sources of coarse and fine particles (adapted from CEPA/FPAC, 1998; Environment Canada *et al.*, 2000; Sloss, 1998; Smith *et al.*, 1998; U.S.EPA, 1996).

NATURAL		ANTHROPOGENIC	
Primary	Secondary	Primary	Secondary
PM $_{2.5}$			
Wildfires, sea spray, volcanic activity, viruses, bacteria.	Organic carbons from biogenic VOC's, Nitrates from natural NO_x, oxidation of reduced sulfur gases emitted by oceans and wetlands; and SO_2 and H_2S emitted by volcanism and forest fires, NH_3 emissions from wild animals and undisturbed soil.	Fossil fuel combustion (industrial, residential), vehicles, residential wood combustion, fugitive dust (roads, agriculture, forestry), open burning, break/tire wear.	Organic carbons from anthropogenic sources of VOC's (vehicles, industrial processes, solvents), sulphates and nitrates from sources of SO_x and NO_x (vehicles, power plants, etc.), NH_3 emissions from animal husbandry, fertilized land, sewage.
PM $_{10}$			
Fugitive dust, sea spray, pollen, spores, bacterial agglomerates.		Mineral dust from mining and extraction industries, windblown agricultural soil, road dust, tire and brake wear, dust from construction sites.	

Tucker (1998) hypothesized that constituents of combustion PM may be on average more toxic than constituents of fugitive PM. The following table (Table 2-3) lists the major outdoor sources of PM_{10} emissions for Canada and Alberta.

Table 2-3: Major sources of PM_{10} emissions (t) in 1995 for Canada and Alberta (adapted from Environment Canada *et al.*, 2000)

SOURCE CATEGORY	CANADA	ALBERTA
Industrial Sources	287 000	38 500
Non-industrial fuel combustion (Power utilities, commercial and residential fuel combustion)	179 000	17 900
Transportation	96 000	13 000
Incineration	1 470	16
Miscellaneous (Cigarette smoking, structural fires, Pesticide/Fertilizer application, marine cargo handling, etc.)	14 400	1 940
Open Sources (Agriculture, construction, mine tailings, road dust, etc.)	4 793 000	1 509 000
Total	5 371 000	1 581 000

The data available for Canada indicate that source contributions for primary particles vary by region. Industrial sources of PM are important in all provinces except Prince Edward Island, where residential wood combustion is an important source. Non-industrial fuel combustion is a significant source of PM in Alberta. Forest fires and prescribed burning are the largest PM sources in Saskatchewan, British Columbia and the North-West Territories (Environment Canada *et al.*, 2000).

2.5.2 Indoor Sources

Indoor particulate matter can originate from either outdoors or indoors. Fine particles readily penetrate buildings; penetration rates of 0.6-1 have been reported. Coarse particles probably penetrate less effectively (Tung *et al.*, 1999, Wallace, 1996). Human activity such as people movement and cleaning activities lead to resuspension of particles, thus increasing PM available for inhalation. Table 2-4 provides an overview of sources of indoor particles and their origin.

Table 2-4: Indoor sources of particulate matter
(adapted from CEPA/FPAC, 1998; Health Canada, 1989; Tucker, 1998; U.S. EPA, 1991; U.S.EPA, 1996)

INDOOR ORIGIN	OUTDOOR ORIGIN	RESUSPENSION OF PARTICLES OF EITHER INDOOR OR OUTDOOR ORIGIN
Smoking, cooking, space heating (kerosene, wood), ventilation systems, humidifiers, office equipment, dust mites, pets, diseased people (bacteria, viruses) personal activities (hobbies) maintenance/renovation	Outdoor air (through infiltration, ventilation), tracked-in soil, carried-in dusts from industrial workplaces or other places.	Cleaning activities, maintenance/renovation activities, people/ pet movements.

Several authors noted that the major source of indoor particles in homes with smoking activity is cigarette smoke (Anon, 2000; Dockery *et al.*, 1981; Health Canada, 1989; Jones *et al.*, 2000) . Spengler (1985) reported on the Kingston–Harriman portion of the Harvard Six-City Study and found that indoor concentrations of $PM_{3.5}$ in homes with smokers averaged 74±7 $\mu g/m^3$, compared to 28±1 $\mu g/m^3$ in homes without smoking.

Wallace (1996) estimated an increase in PM concentrations ranging from 25 $\mu g/m^3$ to 45 $\mu g/m^3$ due to smoking activity in homes. Several studies identified cooking as a second important source of particles (Abt *et al.*, 2000; Jones *et al.*, 2000; Kamens *et al.*, 1991; Ozkaynak *et al.*, 1996).

2.5.3 Indoor/Outdoor relationship of PM concentrations

Several studies have examined the indoor/outdoor relationship of PM (Abt *et al.*, 2000; Jones *et al.*, 2000; Kulmala *et al.*, 1999; Pellizari *et al.*, 1992; Quackenboss *et al.*, 1989). The indoor/outdoor (I/O) ratio is an indicator for evaluating the difference between indoor and outdoor levels. Their correlation can imply a source relationship between the indoor and outdoor environment (Lee *et al.*, 1999). Generally it was found that the indoor/outdoor ratio of PM is a function of:

- indoor sources which are highly influenced by indoor activities, particularly those relating to the generation and resuspension of PM,
- outdoor PM levels,
- air exchange rates, which are dependent on building characteristics and to some extend on climate (in warmer climates air exchange rates tend to be higher due to open windows and doors),
- the penetration factor, which represents the fraction of ambient PM penetrating indoors, and
- the deposition of PM.

The Particle Total Exposure Assessment Methodology (PTEAM) study measured personal and micro-environmental PM_{10} and $PM_{2.5}$ concentrations in a probability based sample of 178 persons and homes in Riverside, California (Thomas *et al.*, 1993).

Stationary indoor monitors were used to collect samples in the main living area of the home, stationary ambient monitors were used to collect particles outside the home, preferably near the front entrance. These samples were collected concurrently with personal samples. Further ambient samples were collected at a central monitoring site. All homes were non-smoking homes. Air exchange rates were determined for each household. The mean daytime indoor PM_{10} concentration was 78 $\mu g/m^3$ and the mean daytime outdoor PM_{10} concentration was 83 $\mu g/m^3$. At nighttime, the mean indoor PM_{10} concentration was 53 $\mu g/m^3$ and the mean outdoor PM_{10} concentration was 74 $\mu g/m^3$. Daytime mean personal exposure was 129 $\mu g/m^3$, night time mean personal PM_{10} was 68 $\mu g/m^3$. The mean air exchange rate was 0.75 /h.

Correlation analysis found moderate correlation for indoor-outdoor concentrations and personal – indoor concentrations but low correlation for personal-outdoor concentrations. Using the data from this study it was found that the equation governing the indoor/outdoor ratio was determined by two parameters: air exchange and particle deposition rate (Clayton *et al.*, 1993; Pellizari *et al.*, 1999; Thomas *et al.*, 1993).

The average decay rates due to diffusion or sedimentation were estimated for sulphate at 0.16/h, PM_{10} at 0.65±0.28/h, and for $PM_{2.5}$ at 0.39±0.16/h. For the coarse fraction $PM_{10-2.5}$, an average decay rate of 1.01±0.43/h was estimated (Ozkaynak *et al.*, 1996). For a home with no indoor sources and an average air exchange rate of 0.75/h it would imply that fine particles indoors would be about 65% of the outdoor concentration at equilibrium, and coarse particles would be approximately 43% of the outdoor value (Wallace, 1996). Almost none of the homes exhibited concentrations that low, thus it was inferred that most homes had significant indoor sources of PM.

Colome *et al.* (1992) examined PM levels inside ten homes – nine were inhabited by asthmatics. PM_{10} samples were taken inside and outside the homes. It was found that the concentration inside homes was lower than the outdoor concentrations. It was suggested that this was most likely due to the fact that asthmatics avoid triggers of attacks such as smoking, pets, and certain cleaning compounds. A moderate correlation of indoor with outdoor concentration was established, thus it was concluded that the variation in indoor concentration was driven by outdoor PM levels. The building provided protection against outdoor PM, thus a reduction in air exchange combined with an absence of indoor sources may be a strategy to protect the sensitive segments of society from particulate matter (Colome *et al.*, 1992).

Quackenboss *et al.* (1989) collected 149 PM_{10} samples in homes with and without smokers. Indoor/outdoor ratios of 0.63 for the non-smoking homes were found and a ratio of 1.2 for the homes with smokers. It was concluded that ambient measurement of PM_{10} would over predict indoor exposure in non-smoking households and under predict exposure for inhabitants of smoking households (Quackenboss *et al.*, 1989).

Abt *et al.* (2000) sampled continuous particle size and mass concentration data in four homes with each home monitored for one or two six-day periods. Activity and air-exchange data were also collected. Indoor concentrations were strongly correlated with outdoor concentrations except for the ultra fine ($PM_{0.02\text{-}0.1}$) and coarse ($PM_{2.5\text{-}10}$) fraction that exhibited lower correlation coefficients. The lower correlation coefficients for the ultra fine and coarse fraction may be a result of particle loss due to the deposition or due to the generation of particles indoors. Additionally, it was found that air exchange rates influenced the indoor/outdoor relationship significantly. Lower air exchange rates (<1/h) corresponded to elevated particle concentrations as a result of longer air residence times that allowed the accumulation of particles from indoor sources (Abt *et al.*, 2000).

2.6 Seasonal Variability of Particulate Matter

Data collected in several studies indicate that there are seasonal patterns to particulate matter concentrations. Seasonal variation can occur due to changes in emissions, meteorological conditions (seasonal changes in atmospheric mixing patterns), changes in rates of chemical reactions due to changes in temperature, hours of daylight, and humidity (Lipfert, 1998).

The U.S. EPA (1996) states that PM_{10} concentrations exhibit peaks during the summer in both urban and non-urban sites in the southeast, northeast and industrial Midwest of the United states, whereas the northwest urban PM_{10} concentrations show a spring and early summer minimum. The non-urban PM_{10} concentrations for the northwest show a summer peak similar to the profile of the northeast. In the southwest (California), seasonal profiles show fall peaks for urban locations, while the non-urban locations have a flat peak maximum from spring to early fall. The concentrations of the fine fraction exceeded the coarse fraction ($PM_{2.5-10}$) at urban and non-urban sites (U.S.EPA, 1996).

Chow *et al.* (1994) reported on the Southern California Air Quality Study (SCAQS). Samples were taken at six sampling sites during the summer and fall 1987 and three additional sampling sites during the summer. The sampling sites were located in the South Coast Air Basin that occupies more than 16,000 km^2 of the non-desert portions of Los Angeles, Riverside, Orange County and San Bernardino. Sampling days were chosen by meteorological forecast to capture the highest $PM_{2.5}$ and PM_{10} concentrations. PM_{10} mass concentrations were found to be highest during the fall and were dominated by

$PM_{2.5}$. The authors concluded that elevated fall levels were due to limited ventilation, intense nighttime inversions, and coupling of the surface to the mixed layer only during the daylight hours (Chow *et al.*, 1994).

Cheng *et al.* (1998) reviewed particulate matter data collected from 1984 to 1994 in Edmonton and Calgary. It was concluded that fine particles exhibited a seasonal pattern in both Calgary and Edmonton, with higher concentrations occurring during the winter. Coarse PM was higher during the winter in Calgary and during springtime in Edmonton. The drop in coarse PM concentrations in Edmonton during the wintertime was attributed to total snow cover, whereas in Calgary winter Chinooks melt the snow cover and expose soil at various times throughout the winter (Cheng *et al.*, 1998).

A study conducted in homes in Boston, Massachusetts during the winter and summer of 1996 found the ultra fine PM fraction to be substantially elevated during the summer. This was attributed to the formation of sulfate and other secondary particles from photochemical reactions. The coarse fraction was elevated during the summer time, which may have resulted from an increase in resuspension due to drier conditions or to pollen. Correspondingly, summer indoor concentrations were significantly higher than during the winter. The author concluded that this is indicative of the influence of outdoor concentrations on indoor concentrations (Abt *et al.*, 2000).

2.7 Human Exposure to Particulate Matter

Human exposure to particulate matter occurs in different microenvironments. Complete assessment of exposure to PM has to take into consideration different microenvironments such as the home, work, outdoors, and others such as direct inhalation of cigarette smoke. A microenvironment can be defined as "a volume in space with dimension dX, dY, and dZ during an interval of time dt, for which the variation of concentration within the micro-environment is less than the variation between the microenvironment and its neighbouring microenvironments" (Zartarian *et al.*, 1997). Duan (1982) defined microenvironment as "a chunk of air space with homogenous pollutant concentration". The majority of actual exposure will most likely occur indoors as North Americans spend up to 90% of their time in indoor environments (Chapin, 1974; Health Canada, 1989; Szalai, 1972).

People in a community surrounding an ambient monitoring station will, over time, be exposed to similar concentrations and compositions of ambient fine PM. Exposure to coarse PM may vary due to local effects. Exposure to non-ambient fine PM will be widely different as personal activities such as smoking, hobbies and occupation varies.

The main pathway of exposure to PM is through inhalation, thus the prime target for effects of inhaled PM is the respiratory tract. Figure 2.4 illustrates a model of source, exposure, dose, and health response as it applies to the respiratory tract as the target organ.

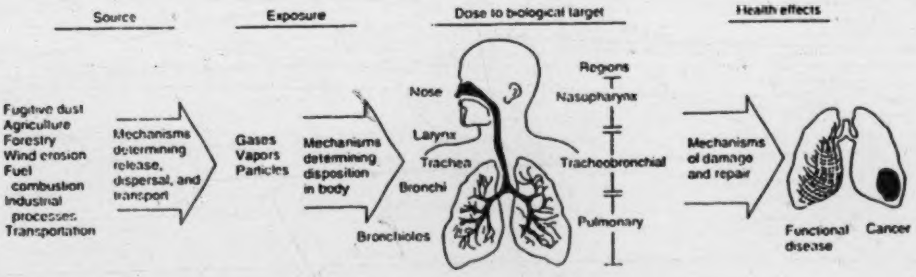

Figure 2.4: A continuous model linking source with health response (McClellan *et al.*, 1997).

The primary function of the respiratory tract is movement of gases from the nose or mouth via the airways to the alveolar region and the exchange of gases; oxygen moves into the body and carbon dioxide is removed from the body. Respiratory and cardiovascular functions are closely matched to facilitate the gas exchange. Other functions of the respiratory tract are detoxification, or activation of inhaled chemicals, blood reservoir, as well as a key role in acid-base balance. Each of those functions could be altered through inhalation of PM (McClellan *et al.*, 1997).

Another consideration when estimating exposure is physical activity as it determines the ventilation rate. The average ventilation rate during the day at work is 20 l/min and the ventilation rate during sleep is 8 l/min (Mage, 1985). Considering that PM concentrations tend to be higher during the day (Pellizari *et al.*, 1992), combined with an increased average ventilation rate during that period of time, it can be expected that the potential for exposure to PM is higher during the day than during the night.

The volume of air inhaled is an important determinant regarding the amount of PM that is deposited in the respiratory tract. Other factors affecting deposition and retention are the physical and chemical characteristics of PM. Particle deposition in the respiratory tract is a function of aerodynamic diameter and ventilation rate. Smaller particles ($D_{ae} < 10\ \mu m$) penetrate deeper into the respiratory tract, whereas larger particles are removed in the nasopharynx (Mage, 1985). The nasopharyngeal area extends from the head to the larynx, particles larger than 30 μm D_{ae} are unlikely to enter the nasal passage. Rapid directional changes of airflow in this area favour deposition of the larger particles (> 5μm) due to impaction. The tracheobronchial region extends from the trachea to the end of the terminal bronchioles. In this region directional and air velocity changes decrease, favouring deposition of particles ranging from 1-5 μm. The pulmonary region consists of fine respiratory bronchioles and alveolar ducts. With air velocity decreasing to almost zero fewer particles will reach the alveoli due to increased time for sedimentation. Gravity becomes less important as particles become smaller, resulting in diffusion to alveolar walls becoming the dominant form of deposition (Mage, 1985; Owen *et al.*, 1992; U.S.EPA, 1996).

Removal of particles from the pulmonary region is more difficult than from the upper respiratory tract, thus residence time of particles is longest in the pulmonary region. The rate of removal is affected by dissolution into the surrounding fluids or tissue. The rate of dissolution is influenced by the solubility of the material in the body fluids and by the surface area of the particle. Once particles are deposited, aerodynamic diameter will become second in importance to particle surface area and their solubility. The smaller the particles, the greater the surface area relative to their mass, which facilitates more rapid dissolving of particles. The fate of the chemical constituents of particulate matter is now dependent on the chemical's properties and the metabolism of chemicals by the respiratory tract (McClellan *et al.*, 1997; Owen *et al.*, 1992; U.S.EPA, 1996). Therefore, analysis of the chemical composition of different size ranges is useful to allow an estimation of dose of the different chemicals deposited in the different areas of the respiratory tract.

2.8 Health Effects of Particulate Matter

While there is still uncertainty regarding the precise mechanisms causing health effects it is generally accepted that even low levels of PM can have effects on human health (Binkova *et al.*, 1999; Dockery *et al.*, 1992; Englert, 1997; Environment Canada *et al.*, 2000; Gavett *et al.*, 1999; Jedrychowski, 1999; Smith *et al.*, 1999; Tucker, 1998; U.S.EPA, 1996).

The effects on human health from exposure to PM_{10} can be chronic or acute: chronic illnesses include permanent degeneration of respiratory functions, bronchitis and premature death. Acute effects include temporary changes in respiratory functions and increased rates of hospitalization due to cardio-pulmonary attacks. Furthermore, aggravated respiratory infections, asthma, emphysema, coronary pathology and lung cancer have been observed (Labelle, 2000, Burnett *et al.*, 1997). The elderly, children, and people with chronic lung disease or asthma, may be especially sensitive to the effects of particulate matter (U.S.EPA, 1996). Generally, the likelihood of becoming ill from a contaminant will depend on the individuals' sensitivity to the contaminant, the concentration of the contaminant, the current physical and psychological health, and the frequency and duration of exposure (Jones, 1999).

The majority of epidemiological studies investigated the link between mortality and exposure to PM_{10}. While there are remarkable consistencies among the U.S. studies independent of location, the U.K. Department of Health identified modest differences between U.S. and European studies. An explanation for these differences was not provided.

Overall total daily mortality increased by 1% per 10 $\mu g/m^3$ increase in PM_{10} concentration (Harrison *et al.*, 2000). The authors stated further that the finding applied to both developed and developing countries, and equally to the eastern and western United States where PM composition is very different. While the consistency of the epidemiological data increased the confidence in the reported results, the U.S. EPA identified the following remaining uncertainties (U.S.EPA, 1996):

- the shape of the PM exposure-response relationship,
- the time over which health effects are manifested,
- PM constituents responsible for observed health effect,
- the transferability of findings in one locations to other locations,
- the nature and magnitude of overall public health risk, and
- the magnitude and variability of risk estimates for PM.

The WHO did not recommend guidelines for short-term or long-term average PM concentrations as a consequence of the above uncertainties. Instead risk estimates were provided as guidance in setting of standards (Englert, 1997).

2.8.1 Other effects of Particulate Matter

Other effects of particulate matter are soiling of surfaces indoors and outdoors, a detrimental effect on vegetation, and reduction in visibility. While the first effect is mainly a nuisance, high deposition of cement dust on vegetation, for example, can lead to a decrease in overall yields on cereals. Impairment of visibility can seriously affect traffic on highways and at airports. Furthermore, the public perceives the haze generated by particles as an indicator of poor air quality, thus it may impact the perceived quality of life (CEPA/FPAC, 1998).

2.9 Sampling and Analysis of Particulate Matter

2.9.1 Particle Samplers

Particle filtration samplers are generally active samplers that consist of a size-selective inlet, filter media, filter holder, flow meter and an air pump. The sampling inlet removes particles that exceed a specified aerodynamic diameter. Removal is achieved via direct impaction, virtual impaction, cyclonic flow or selective filtration (Keith, 1996). Size selective inlets should be independent of wind speed and direction. The particle diameter collected by a particular inlet is dependent on the flow rate. Inlet flow rates are defined as high volume (1000 l/min), medium volume (100 l/min), low volume (10-20 l/min) and mini volume (5 l/min).

Impaction inlets consist of circular jets positioned above an impaction plate. Particles smaller than the specified D_{ae} follow the streamlines as they bend at the impaction plate; particles larger than the specified D_{ae} will impact on the plate. Impaction plates can be greased to eliminate particle bounce. Virtual impaction operates on a similar principle with the exception that the impaction plate has been replaced by an opening which directs the larger particles to one sampling substrate while the smaller particles follow the streamlines to another substrate. Cyclonic flow inlets use an impeller to impart a circular motion onto the air entering the inlet. The air enters a cylindrical tube perpendicular to the impeller. The centripetal force imparted on the particles drives them toward the walls of the tube. The particles reaching the walls either adhere to the wall or drop into a hopper at the bottom of the tube. Selective filtration uses polycarbonate filters with a uniform pore size and known sampling effectiveness to collect large particles on a pre-filter, and pass smaller particles to a back-up filter (Chow *et al.*, 1998).

After passing through the inlet, the air is drawn through a filter that retains the suspended particles. Common filter materials are cellulose fiber, glass fiber, Teflon© membrane, polycarbonate membrane, quartz fiber, and nylon membrane (Keith, 1996). Different filter materials have different advantages and disadvantages that have to be considered for their intended application. The filter material has to be chosen so it is compatible with subsequent analysis methods. Chow *et al.* (1998) provide a good description of filter materials and applications.

Since particle collection characteristics are dependent on airflow rate, the quantity of air drawn through the inlet per unit time must be controlled and measured to maintain the size-selective properties of the inlet and determine the concentration of PM.

Other samplers available are continuous samplers: the Beta Attenuation Monitors (BAM) and the Tapered Element Oscillating Microbalance (TEOM). The BAM attenuates beta rays (electrons with energies from 0.01-0.1 MeV) emitted by a radioactive source when they pass through particles deposited on a filter. Beta-ray attenuation is related to PM mass collected on the filter. Initially blank attenuation is measured by drawing a filter tape between the beta emitter and the detector, then across an area where particles are collected on the tape, the beta attenuation measurement is repeated and the blank corrected attenuation readings are converted to mass concentrations with averaging times of 30 minutes or more. The TEOM collects particles continually on a filter mounted on the tip of a glass element to which an electrical field is applied that causes the element to oscillate. Air is drawn through the filter and the glass element. The oscillation frequency of the element decreases with increased mass on the filter, thus inertial mass is measured directly (Chow *et al.*, 1998; Keith, 1996).

2.10 Analysis of PM Samples

Particulate mass is measured by weighing a filter before and after sample collection and subtracting the initial weight from the final weight. The US EPA reference method requires equilibration of filters for 24h at a constant (± 3 °C) temperature between 15 and 30°C and constant (±5%) relative humidity between 20 and 40% to minimize loss of volatile species and liquid water associated with soluble compounds. Balance sensitivity should be better than 100 μg for high volume samples and 1 μg for low volume samples. Further, the work area should be dust-free, and gloves should be worn (U.S. EPA, 1996).

Other analytical options to determine the composition of PM are elemental analysis, water-soluble ion analysis, carbon analysis methods, and individual particle analysis. Discussion of these is beyond the scope of this thesis.

2.10.1 Errors Associated with PM Sampling

Errors in PM measurements may arise during sample preparation, sampling, transport of the sample, and at the laboratory (Lodge *et al.*, 1989). The following table (Table 2-5) provides an overview of the potential sources of error during the sample collection process.

To address potential errors, a rigid quality control procedure consisting of proper maintenance and calibration of sampling equipment, choice of appropriate materials, and consistent filter handling and laboratory procedures has to be implemented (Chow, 1995; Keith, 1991; Keith, 1992; Keith, 1996; Taylor, 1987).

Table 2-5: Potential sources of error associated with particulate sampling
(after Lodge *et al.*, 1989; Keith, 1991; Keith , 1996, Chow *et al.*, 1998)

SAMPLER ERROR	LABORATORY ERROR	TRANSPORT ERROR
Loss of semi-volatile components, ambient temperature (<-30°C, > 45 °C), sampler malfunction, sampler age and cleanliness, sampler leakage, flow rate and sampling time, sampler design, variable weather conditions, particle removal in inlets, passive deposition and recirculation.	Inadequate conditioning /equilibration, filter handling and storage, filter weighing, electrostatic charge.	Protective container failure, handling and storage, humidity fluctuations, temperature fluctuations.

While the use of quality control procedures may not eliminate errors entirely; a reduction of errors to a minimum is desired.

2.11 Design of Community Based Study

By far the most extensive investigation regarding human exposure to particulate matter was undertaken in Riverside California during the fall of 1990 (Thomas *et al.*, 1993). Therefore, this study is discussed in detail. The study was modeled after the Total Exposure Assessment Methodology (TEAM) approach. The four basic demands of the TEAM approach are:

- a representative probability sample of the population of concern,
- direct measurement of the pollutant concentration affecting people through relevant media,

- direct measurement of body burden,
- recording of people's daily activities.

2.11.1 PTEAM Study

The objective of the PTEAM study was to estimate the frequency distribution of PM_{10} total exposure in an urban population. $PM_{2.5}$ and elemental concentrations were measured to provide source characterization data. These data, in conjunction with toxicological data for human exposure to PM, are useful for performing health risk analysis. The study consisted of three stages: during the first stage the methodology necessary for personal exposure to PM_{10} was developed and tested (Thomas *et al.*, 1993). During the second stage the methodology for measuring personal, indoor and outdoor PM_{10} and $PM_{2.5}$, as well as questionnaire designs were tested in a nine home study in Southern California (Clayton *et al.*, 1991). This review focuses on the third stage or main component conducted during the fall of 1990. It attempted to meet the PTEAM study objectives by:

- obtaining probability-based monitoring information to determine the frequency distribution of exposure,
- measuring human exposure to PM for health risk assessment,
- defining the relationship between personal exposure, micro-environmental/ambient air levels and outdoor air standards of certain areas,
- determining the source of PM by developing a source apportionment or source-receptor model for exposure to PM using source profile and mass measurement data, and
- using questionnaires to assess the frequency of exposure to sources.

Further, the study examined differences between the various samplers utilized in the study.

To investigate the relationship between indoor concentrations and air quality standards, PM_{10} needed to be considered. $PM_{2.5}$ was considered because it is the fraction that reaches the alveolar region of the lung thus this data could be useful in conjunction with epidemiological data to assess health effects (Pellizari *et al.*, 1992). To determine source contribution elemental analysis was performed. Additionally, the elemental analysis enhanced the understanding of chemical exposure from the observed particles. Questionnaires helped in identifying activity-source occurrences leading to potential exposure to elements. Nicotine was measured as a tracer of environmental tobacco smoke (ETS) to assess the contribution of ETS to a person's exposure to PM. Semi-volatile and volatile particle-bound organics were measured as an indicator for mutagenicity and carcinogenicity. Air exchange data were obtained for source characterization purposes.

From the target population of 139,000 ±16,000 non-smoking residents ten years of age and older, 178 participants were randomly selected and their homes were monitored for two consecutive 12 hour periods. During sampling, a personal PM_{10}, indoor PM_{10} and $PM_{2.5}$, and outdoor PM_{10} and $PM_{2.5}$ sampler was deployed. Additional samples were collected at a central ambient monitoring station. At the central monitoring station a sampler specifically designed for indoor, outdoor, and personal sampling was collocated with a Wedding High Vol reference method sampler and a dichotomous sampler to assess comparability of the different sampling methods. Requirements for the central monitoring site were: provision of representative samples for the area, meeting siting requirements for reference method PM_{10} monitoring, access to power, security, and providing convenient access.

Indoor samplers were deployed in the main living area of the house at least 2 m away from exterior doors, windows, and ventilation registers and 0.6 meters from the wall. Sampling heads were attached approximately 1 m above the floor, which represents the breathing height of a person when seated. The outdoor sampler was deployed at least 1.5 meters from the wall facing the street outside of the main living area of the home, 1 meter away from any trees and bushes, at least five meters away from any type of vent, and at a height of approximately 1.7 meters. For the personal sample, the impactor was worn on the participant's lapel; the participant's breathing zone. The pump was worn in a fanny pack that was worn around the waist. During sleeping and showering, the personal sampler was placed as close to the participant as possible (Clayton *et al.*, 1993).

A rigid QA/QC protocol was adhered to that consisted of field and lab blanks (10%), collocated samples (5%), sampler and balance field audits, intra and inter-laboratory replicate elemental analysis and rigid sample handling and analysis protocols. Sample mass was determined gravimetrically; elemental analysis was performed using energy dispersive X-ray fluorescence (XRF).

Table 2-6 provides the distribution of the 24-hour PM_{10} concentrations. The mean indoor/outdoor concentration ratio for PM_{10} was 0.93 (0.056), the personal/indoor ratio was 1.6 (0.062), and the personal/outdoor ratio was 1.5 (0.089) during the daytime. At night, the indoor/outdoor ratio was 0.70 (0.035), personal/indoor ratio was 1.2 (0.044) and personal outdoor ratio was 0.89 (0.036). Values given in brackets are standard errors.

Table 2-6: Distribution of 24-hour PM_{10} concentrations at Riverside, California (after Pellizari *et al*, 1992).

TYPE OF SAMPLE	MEAN CONCENTRATION ($\mu g/m^3$)	RANGE ($\mu g/m^3$)
Personal Exposure (PEM)	113 (6.0)[a]	34-287
Indoor (SIM)	79 (4.1)[a]	20-325
Outdoor (SAM)	91 (4.1)[a]	15-280
Central Ambient Station		
Wedding	67 (5.5)[a]	16-164
Dichotomous	71 (4.9)[a]	15-147
SAM	83 (6.3)[a]	18-181
PEM	80 (5.9)[a]	18-170

[a] values in brackets are standard errors.

Elemental analysis identified 13 elements of primary interest (Si, Al, Ca, Fe, K, Mn, Br, Pb, Cd, As, V, Se, Ni), and seven elements of secondary interest (S, Zn, Cl, Ti, Cu, Sr, Pr). Si, Al, and Ca were found in highest concentrations and were most likely associated with soils (Pellizari *et al.*, 1992).

2.11.1.1 Methodology of PTEAM Study

Target Area

Riverside was chosen as the geographic location as it fulfilled the following design requirements:

- heterogeneous and variable aerosol levels over the study area to allow for determination of correlates of the variability in ambient levels,
- area should not be dominated by a single stationary source,

- heterogeneous housing stock,
- easy availability of size-fractioned particle data for determining relative source contributions, and
- easy access to the site by field personnel to collect samples.

Sampling Season

Fall was chosen as it was determined from temporal fixed-site monitoring data that this is the time during the year when Riverside experiences the greatest range in PM levels. Variable ambient levels of PM would facilitate establishment of relationships between ambient and indoor or personal measurements.

Target Age Range

A wide range in ages of study participants is desirable as it allows for estimation of the relationship between age and exposure to PM. It was assumed though, that children 10 years and younger would experience the wearing of a personal sampler as too great a burden, additionally it was questionable if they would wear it on an ongoing basis as it might interfere too much with their daily activities.

Exclusion of Smokers

Personal sampling of PM cannot account for particles inhaled directly through smoking activity, thus the actual exposure to PM will be underestimated. Most data analysis would have to exclude the participants that smoked as the sample taken would not reflect actual exposure accurately. Since financial restrictions would not allow for a larger sample size, it was decided to exclude all homes where all inhabitants smoked, but include participants who lived with smokers.

Statistical Design

The study design was a stratified 3-stage household sampling design. The first stage sampling units were "blocks" as defined for the 1980 Census. Each block was designed to contain at least 30 occupied residences. The first-stage sample was stratified into geographic areas within Riverside, and by dwelling characteristics from the 1980 Census: average house value, and percent detached, single-family dwellings. Geographical stratification was chosen to facilitate more efficient sample collection and to ensure that the sample area was representative of the target population. This resulted in a stratified sample of 36 first stage sampling units (areas) selected with probabilities proportional to the housing unit counts.

A sample of 680 housing units was selected by probability sampling from all units listed in the 36 areas: 632 occupied housing units were identified and 443 household screening interviews were completed. The screening interview identified employment and smoking status, and age.

A total of 257 sample persons were selected. People were selected so that person-level probabilities were approximately equal. People who worked at least 30 hours per week outside the home and people exposed to passive smoke in their homes were slightly oversampled relative to their representation in the survey population because of the potential for elevated exposure. A subsample of 181 housing units were selected for indoor phthalate and PAH monitoring, and a subsample of 98 units were selected for outdoor phthalate and PAH monitoring. Initially a fourth stage had been planned which randomly selected a sampling day for each participant. However, this procedure was abandoned early in the study as it resulted in unfilled appointments, which would have lead to a lengthening of the study and an increase in cost. A total of 178 persons completed the study thus giving a monitoring–phase response rate of 69.3% (178/257), and an overall study response rate of 48.5%.

Three questionnaires were administered during the study: a Household Screening Questionnaire (Q1), a Household Characteristics Questionnaire (Q2), and a 12-hour Time Activity Survey (Q3). The Household Screening Questionnaire was used in the second stage, the Household Characteristics Questionnaire was used in the third stage, the Time Activity questionnaire was administered immediately after each 12-hour sampling period. Q1 collected information on number of inhabitants, age, address, occupation, and smoking status, Q2 collected information on physical building characteristics, participant characteristics such as race, occupation, indoor-outdoor time budgets, Q3 sought to identify potential exposure influence during the monitoring period such as cleaning activities, hobbies performed, use of heating/ventilation devices, presence of smoke etc.

The following provides a brief overview of the findings:

- personal PM_{10} concentrations were up to 50% higher than mean daytime PM_{10} concentrations measured indoors, outdoors, or at the central ambient location. This indicates that ambient air monitoring underestimated personal exposure to PM_{10},
- overnight personal exposure also exceeded indoor levels,
- a diurnal trend could be observed with PM_{10} concentrations being higher during the day,
- 25% of the population's 24h exposure exceeded the 24h PM_{10} U.S. standard (150 $\mu g/m^3$),

- 90% of the population's exposure exceeded the California Ambient Air Quality Standard of 50 $\mu g/m^3$,
- people performing housework had significantly higher exposures than people working outside the home,
- homes with smoking activity had higher PM_{10} and $PM_{2.5}$ levels,
- outdoor concentrations near the homes were well correlated with ambient concentrations at the central site. (Pellizari *et al.*, 1992).

2.12 Conclusions from the Literature Review

Personal sampling is by far the most accurate measure of actual human exposure to PM. It would not be implemented in this study, as carrying a personal sampler is perceived too large a burden on the study participants. Other studies (Anon, 2000) opted to recruit volunteers to achieve their monitoring goals. It was felt that it was important to maintain a probability sampling scheme to allow for inferences from the sample to the target population and allow for comparison of the data with that obtained from future studies. Additionally, the majority of household inhabitants smoked, thus PM directly inhaled would not have been measured by the personal PM sampler, resulting in underestimation of actual exposure.

While obtaining $PM_{2.5}$ data would have been desirable, as it appears to be the more relevant fraction of particulate matter regarding human health, it was known from monitoring results at the WBEA meteorological station that $PM_{2.5}$ ambient levels in Ft. McKay are low. To avoid obtaining a large amount of below detection data, PM_{10} was chosen as the PM size fraction to be monitored.

Questionnaires were used in the PTEAM and Alberta Oilsands Community Exposure and Health Effects Assessment Program (Anon, 2000; Pellizari *et al.*, 1992). They are an essential tool in determining potential sources of a pollutant, thus aiding in the understanding of results. They are a relatively inexpensive method to elicit information from participants, and, if well designed, can be easily administered. Identification of physical building characteristics, household member characteristics and specific activities that may generate PM during the sampling period were the primary objective of the questionnaires developed for this study.

The PTEAM study used probability sampling to randomly select participants. It was felt that this would be an important design feature for this study. Probability sampling methods allow the most defensible basis for inferences from a sample to the target population from which the sample was collected (Williams, 1978). This is also an important aspect if other PM studies are to be performed at some point in the future to compare then current PM_{10} levels with the 1999/2000 PM_{10} levels.

Review of studies provided information regarding placement of samplers, which was adapted for this study. Sampling height, as well as location within the building and outside the building were considered in the design of this study (Micallef *et al.*, 1998; Micallef *et al.*, 1999; Pellizari *et al.*, 1992).

3 Materials and Methods

3.1 Survey Design

3.1.1 Target Area and Time Period

The target population for the study were 129 single-family residences in the community of Ft. McKay, Alberta, Canada. The single-family residences consisted of houses and manufactured homes. Data collection was scheduled for early fall of 1999 and winter of 2000 to account for seasonal variation. A change in particulate matter concentrations can be expected due to the presence of snow cover during winter. Cheng et al. (1998) reported that fine particles show a seasonal pattern in Edmonton and Calgary, with slightly higher concentrations in the winter; coarse particles were generally lower during the winter in Edmonton and Calgary due to snow cover (Cheng *et al.*, 1998).

3.1.2 Sampling Frame

The sampling frame for the study was based on a housing list provided by the Ft. McKay band office. The list included housing type, resident name, and a map reference for each unit. Field staff were sent out to count the dwellings and ensure the accuracy and completeness of the provided list. A map of Ft. McKay was used as an aid in the identification of dwellings (see Figure 3.1). Additionally, Metis housing needed to be identified as it was not included on the list provided by the band office. The updated list consisted of 89 houses, 40 manufactured homes, one duplex, and one threeplex. The multiple-family residences were excluded, therefore leading to a total of 129 single-family residences.

Due to the small size of the community, it was decided to sample 30 households so that the central limit theorem could be applied. The central limit theorem states that the sampling distribution of the sample mean will be approximately normal if the sample size is equal or greater than 30 (Box *et al.*, 1978).

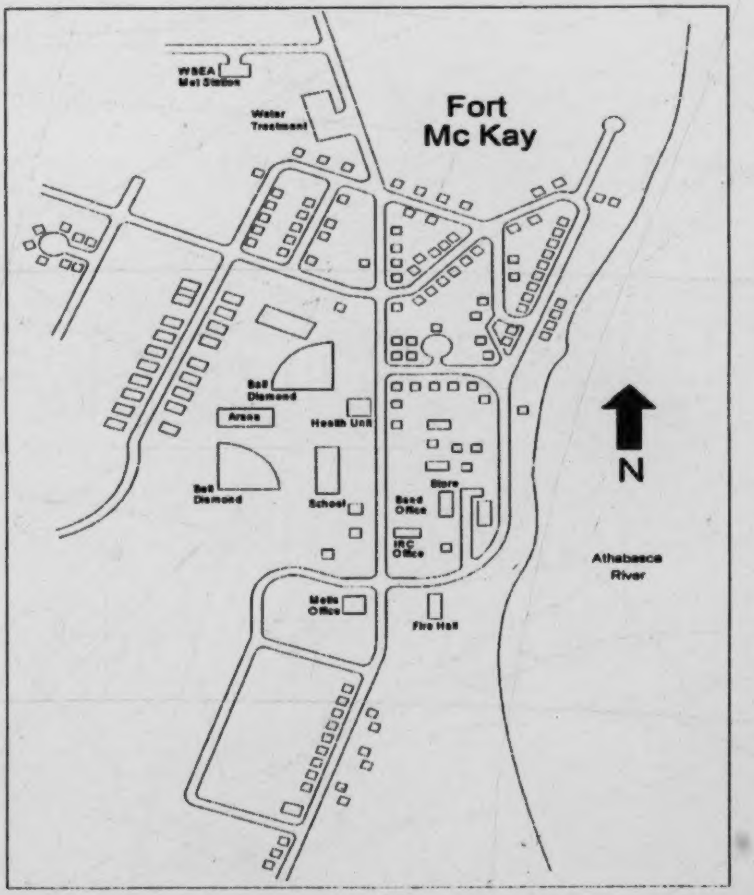

Figure 3.1: Map of Ft. McKay.

3.1.3 Statistical Sampling Design

A probability sampling design was used to select study participants to be monitored. Probability sampling refers to the use of a specific method of random selection (Gilbert, 1987). Probability sampling methods allow for the most defensible basis for inferences from a sample to the target population from which the sample was collected (Williams, 1978). This is an important aspect if another PM study is performed in Ft. McKay at some point in the future to compare PM levels with those measured in this study. Additionally, probability sampling provides a defensible basis for calculating standard errors (Gilbert, 1987).

The statistical design involved stratified random sampling. Stratified random sampling is a design where the target population is divided into non-overlapping strata for the purpose of getting a more precise estimate of the overall population parameter. Division into strata should be done in a manner such that physical samples within a stratum are more similar to each other than to samples from other strata (U.S. EPA, 1998).

The population was divided into two strata, houses and manufactured homes. It was felt that the building characteristics of the two housing types were different – i.e building materials used, absence of basements, thus stratification would lead to a more homogenous grouping. Furthermore, approximately half of the manufactured homes are located in a cluster on the west side of Ft. McKay, hence stratification would result in a geographically representative sample. The sample size was allocated proportionally, as no reasonable assumptions about the variance within each stratum could be drawn. Out of a total sample size of 30 dwellings, 21 houses and 9 manufactured homes were selected.

3.1.3.1 Random selection process

Within each stratum, the houses were listed in order according to their list number. The list of houses was then numbered from 1 to 89, trailers were numbered from 1 to 40 and again from 41 to 80, that is each trailer was assigned two numbers between 1 and 80. A table of two-digit random (00-99) numbers was used to select separate random samples for each stratum.

Occurrences of previously selected numbers and numbers not assigned to a house or manufactured home were discarded. The selection of numbers was repeated until a total of 60 households (42 houses, 18 trailers) were selected. Random selection of extra households was performed to account for possible non-response. The field staff was instructed to recruit the first 21 houses and 9 trailers listed. Subsequent households were to be recruited if a commitment to participate could not be obtained, or if the house inhabitants could not be contacted.

3.2 Field operations and methods

3.2.1 Overview

The monitoring program was designed to collect sufficient PM_{10} samples to characterize the exposure of a representative population in Ft. McKay, Alberta, to inhalable particulate matter. Samples were collect during fall, from September 21, through October 21,1999, and during winter from January 19, to February 3, 2000. A total of 30 households were monitored over 24 hours. During each monitoring period one indoor PM_{10}, one outdoor PM_{10} and one ambient PM_{10} at the WBEA monitoring station was collected. An average of two households were sampled each day. During the fall sampling period air exchange measurements and indoor temperatures were obtained.

Outdoor sampling was abandoned after day 1 as one of the outdoor samplers had been vandalized and had to be sent to the manufacturer for repair. The WBEA Ft. Mc Kay Meteorological Station located at the north end of Ft. McKay was chosen as a "safe" representative ambient sampling location. This was done since any further sampler loss would have led to a complete abandoning of outdoor/ambient PM sample collection. The WBEA station was assumed to be representative due to the small size of the community and the absence of local point sources. Ozkaynak (1996) reported that the outdoor concentrations of PM near homes in Riverside, California were well correlated with outdoor concentrations at a central monitoring site, thus supporting the use of a central site as a representation of a wider area (Ozkaynak *et al.*, 1996).

For the winter sampling period five "safe" representative locations were identified within the community to obtain outdoor samples. The community had been divided into five geographical areas. Within each area, one "safe" outdoor sampling location was chosen to be the representative outdoor location for the houses sampled in this area (see Figure 3.2).

In order to allow for smooth field operations a local field coordinator was hired. The field coordinator hired local interviewers, prepared the initial introduction letter of the study to the community, reviewed the questionnaire for ease of understanding and sensitive contents, acted as a general liaison between the survey researcher and the community, and translated documents and conversations into Cree when necessary.

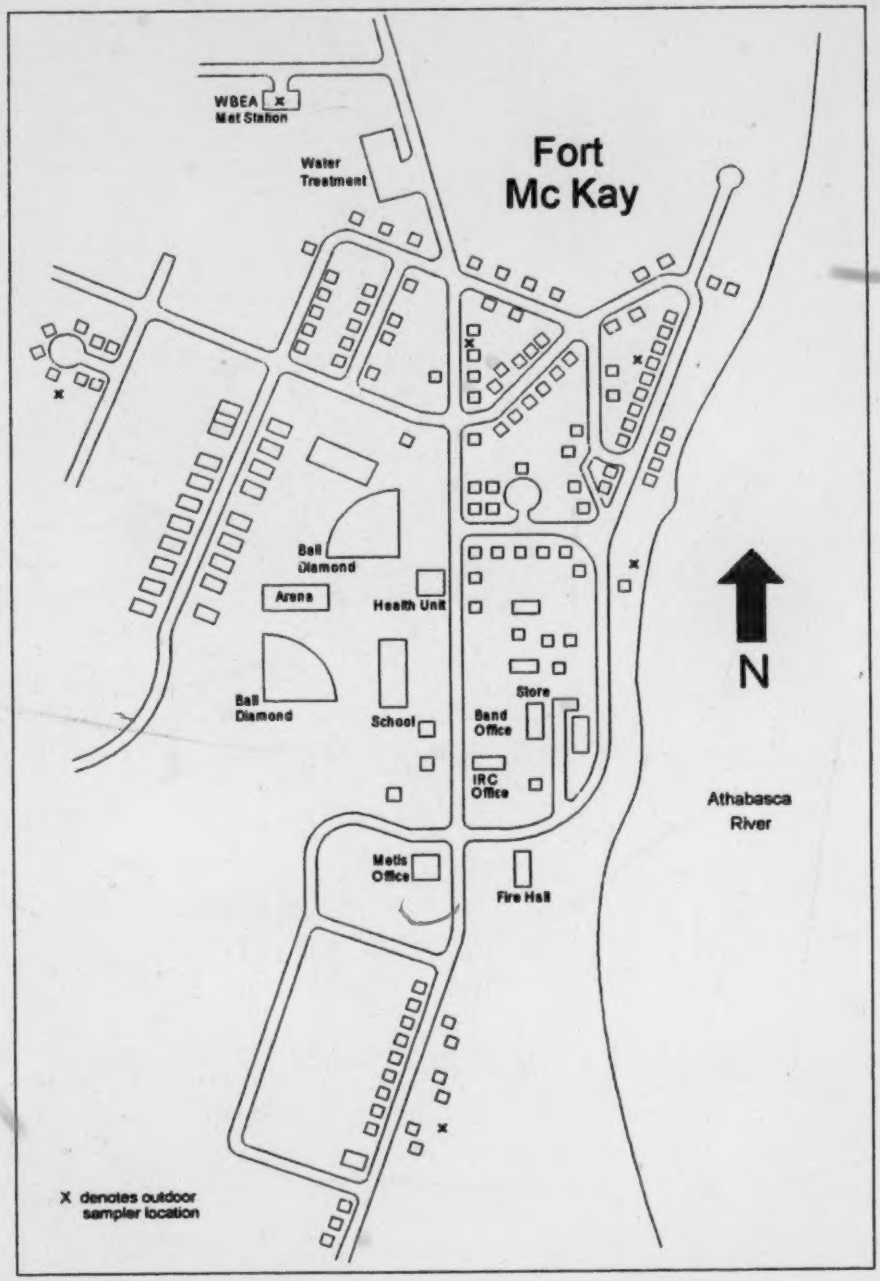

Figure 3.2: Outdoor sampler locations used for winter sampling at Ft. McKay.

The role of the interviewers was to check the accuracy and completeness of the housing list, recruit participants, schedule sampling appointments and fill out the questionnaires with the help of the study participant on the sampling day.

Once in the field, the survey researcher operated in the background, set up the monitoring equipment and only answered questions that the field staff were unable to answer. It was felt that this approach would aid in recruitment of study participants, as they were mainly required to interact with personnel that were familiar to them.

3.2.2 Recruitment Procedures

In August of 1999 an information letter outlining the exposure study was sent out to all residents of Ft. Mckay. The interviewers were given instructions on how to recruit participants and were familiarized with the recruitment materials (Appendix A).

On the first visit, the interviewers were to identify themselves and state the purpose of their visit. The household member was to be asked if they had received and read the information letter. If not, the information letter was to be provided at this point in time. After the letter was read, the household member was given the Participant Information Sheet, which briefly explained the sample collection procedure. This was done to ensure that the participants were aware of the activities at their home during the sampling visits.

The interviewer was then instructed to again briefly explain the study, and show photographs of the samplers to be used in the study. The interviewer was then to outline the commitment required by the participant, and to advise the household member that:

- participation is not obligatory, and commitment to participate can be withdrawn at any time,

- data will be stored at the University of Alberta for 7 years, and
- results of the study can be provided to them when available.

Finally, the prospective participant was to be asked if she/he had any further questions or concerns, and if they would like to participate. If participation was refused, the interviewer was to thank them for their time, complete the Recruit Status Form, and proceed to the next home. If the participant agreed to take part in the study, the Participant Consent Form was to be completed, and an appointment was scheduled.

To aid in scheduling of appointments, the survey researcher provided the interviewer with a pre-printed Sampling Schedule with pre-set appointment times to facilitate efficient sampler deployment and pick-up. Please refer to Appendix A for all forms.

In the event that no-one could be contacted at the home, the interviewer was instructed to attempt contact two more times before choosing an alternate home from the randomly selected list of homes. Recruitment was done during the day-time, evenings, during the week and on weekends. All needed participants were recruited within three weeks. Table 3-1 gives the recruitment success rate; a response rate of 67% was observed. This rate exceeded the expected response rate of approximately 50%. Byrne (2000) and Clayton *et al.* (1993) observed response rates of 45% and 48.5% respectively in similar community-based studies.

One participant dropped out of the study on the first sampling day in the fall; he was replaced with a back-up participant. Furthermore, 13 households that were not on the list of randomly selected homes offered to take part in the study if needed.

Table 3-1: Recruitment response rates for Ft. McKay community exposure study.

	COUNT 1	PERCENT
Total Approached	46	
Consent	31	67%
Refused	5	10%
Never home	10	21%
Drop-out	1	2%

3.2.3 Questionnaires

Questionnaires are an important tool for gathering information that cannot be obtained by any sampling equipment. Questionnaires can provide information regarding the physical properties of the microenvironment, potential sources of the pollutant of interest and activity patterns of the study participants that may contribute to exposure to the pollutant (NAS *et al.*, 1991).

The PTEAM Study utilized questionnaires, which helped in identifying activity-source occurrences leading to potential exposure to PM (Pellizari *et al.*, 1992). The Alberta Oil Sands Community Exposure and Health Effects Assessment Program used questionnaires to identify potential sources in the home and work environments, and identify potential dietary sources of exposure (Anon, 2000).

For this study three questionnaires were developed: Q1 identified physical building characteristics and household member characteristics, Q2 identified activities for the past 24 h, Q3 identified activities for the past 4 days. Identification of specific activities or building characteristics that may generate/contribute to PM, or affect PM concentrations during the sampling period were the primary objectives of the questionnaires developed for this study.

The PM monitoring period was 24 h long. To keep the effort required for filling out questionnaires to a minimum, it was decided to combine the questions for the PM, SO_2 and VOC components of the study. The SO_2 component of the study required a sampling period of four days. To avoid unnecessary duplication of questions, and thus reduce the burden of the study participants, some of the questions of interest for the PM component were included in Q3.

The questions for the PM component were developed based on the PTEAM study questionnaire (Pellizari *et al.*, 1992), the Alberta Oil Sands Community Exposure and Health Effects Assessment Program, and a generic Environmental Inventory Questionnaire (NAS *et al.*, 1991). The questionnaires were reviewed by the field-coordinator for ease of understanding and sensitive content. Further, three test persons from another rural community in Alberta were exposed to the questionnaires and asked for feedback on the clarity and content of the questions.

The interviewers were familiarized with the questions and possible answers so they were able to provide assistance during the interview process if necessary.

3.3 Sampling of PM_{10}

PM_{10} samples were collected for 24 hours indoors and at the ambient location (WBEA Ft. McKay monitoring station) during the fall of 1999, and indoors, outside a representative home, and at the ambient location during the winter sampling period.

For the collection of indoor, outdoor and ambient PM_{10} samples MiniVol portable air samplers were used.

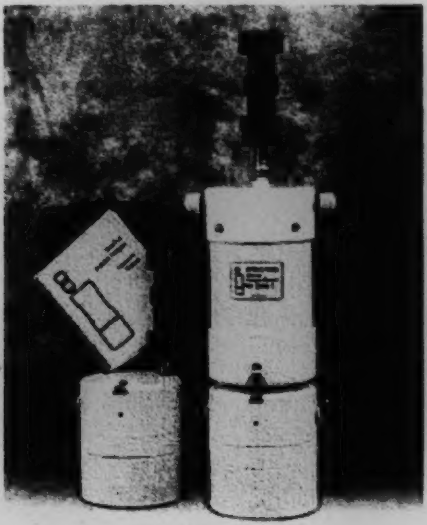

Figure 3.3 MiniVol portable air sampler
(AirMetrics, 2001).

The sampler requirements for this study were: acceptable accuracy and precision, sturdiness, ability to operate as a stand-alone system, simple requirements for sampler siting, small in size, portable, and relatively inexpensive. The MiniVol, manufactured by AirMetrics, gives results that closely approximate data from reference method samplers (Anon, 2000; Hill, 1999; Jones, 1998; LRAPA, 1995; ManTech, 1994; Tropp *et al.*, not dated). Although it has a minimally characterized inlet and a low flow rate, Chow *et al.* (1997), found good agreement between 24-h average PM_{10} mass measurements collected from a MiniVol with a Hi Vol –sampler.

Small in size, lightweight, portable, and battery-operated, the MiniVol is ideal for remote locations, or for use indoors. The MiniVol features a programmable timer, an elapsed time totalizer, AC or DC operation, automatic shut offs for low flow or low battery, 12 AH rechargeable batteries, and durable PVC construction. The MiniVol also features a mounting cradle, which allows for sampler mounting on utility poles and fences (AirMetrics, 1998).

In the particulate mode, ambient air is pumped at 5 liters/minute through a preseparator/filter holder assembly, where particle size separation occurs by impaction, and a sample is collected on a 47mm filter (Figure 3.4).

For the MiniVol the actual volumetric flow rate has to be 5 l/min at ambient conditions to achieve correct particle size separation, thus the sampler had to be adjusted for different temperatures and atmospheric pressures.

At the end of a sampling period, the filter assembly and battery-pack are removed and replaced for the next sampling period. The exposed filters can be analyzed gravimetrically and chemically. The MiniVol has been successfully used in saturation studies, indoor air quality studies, industrial site fenceline sampling, wild fire and

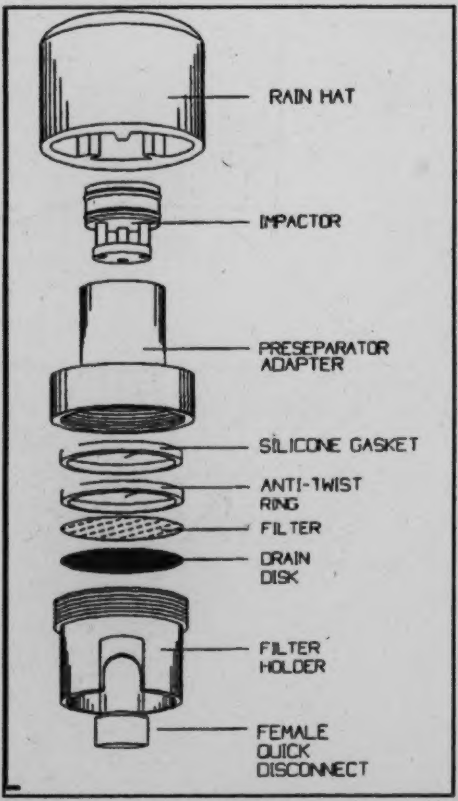

Figure 3.4: PM$_{10}$ preseparator and filter holder assembly (after AirMetrics, 1998)

prescribed burning studies, and urban transportation/air quality studies (Chan *et al.*, 1998; Dolan *et al.*, 1998; LRAPA, 1995; ManTech, 1994; Salter *et al.*, 1999).

A ringed Teflon membrane filter (Gelman Scientific; Ann Arbor, Mi; Teflo®, R2PJ047) was chosen for the particulate sampling. The filter consists of a thin membrane that is stretched between a polymethylpentane ring. It exhibits high particle collection efficiency, a low blank weight, and high flow resistance. It is generally inert to adsorption of gases, exhibits low hygroscopicity, and usually has low blank levels (Chow *et al.*, 1998).

The Teflo® filter is compatible with a variety of analysis methods: gravimetry, optical absorption or light transmission (OA), x-ray fluorescence (XRF), proton-induced x-ray emission (PIXE), instrumental neutron activation analysis (INAA), atomic absorption spectrophotometry (AAS), inductively–coupled plasma with mass spectrophotometry (ICP/MS), automated colorimetry (AC), Ion Chromatography (IC), inductively –coupled plasma with atomic spectrophotometry (ICP/AES). It cannot be used for carbon analysis as it is made of carbon-based materials (Chow *et al.*, 1998). Since the samples collected during this study were scheduled for subsequent elemental analysis, this particular filter type was chosen. Drain disks were placed between the support grid of the bottom half of the filter holder, and the filter to eliminate the support grid pattern from particulate matter deposits on the filters to be used for subsequent elemental analysis.

3.3.1 Sampler Placement

Placement of sampler is an important consideration in obtaining a representative sample. Samplers were placed indoors, outside a representative home and at the meteorological station in Ft. McKay. While it is important to strive for "ideal" sampler placement, realities of the physical surroundings may dictate a compromise.

3.3.1.1 Factors affecting indoor sampling

Sampler location in the indoor environment

The sampler should be placed in a location with free but not forced movement of air, in a room that represents the main living area. Placement near stairs that may exhibit increased vertical air movement due to thermal effects; windows and exterior doors that can have strong drafts should be avoided. Heat registers and return air ducts are areas with strong forced air movement and should be avoided.

Activities indoors

People/animal activity indoors can lead to the generation or resuspension of particulate matter. As the measurement should be a representation of PM levels under "normal" conditions, participants were asked to not change their behaviour. It was the role of the questionnaire to identify activities that may have led to unusual results.

Sampler height

Micallef et al. (1999) measured vertical concentration profiles in an indoor environment and found that the sampling height affects the PM concentration. It was concluded that persons of different height were exposed to different levels of PM. Concentration profiles were determined in a hostel, workshop, library and at a coffee shop. Concentration decreased with height in the workshop and hostel, and peaked at breathing height at the coffee shop. For this study samplers were placed at approximately 1 m height indoors, which represents the breathing height of a seated person, and at 1.70

m outdoors which represents the average breathing height of a standing person (Pellizari *et al.*, 1992).

Ventilation system of the building

The ventilation system of the building can affect airflow patterns and pollutant concentration within the building. While this study did not control for different types of ventilation systems, the type of system, and activities that may alter ventilation characteristics such as opening windows, use of fans etc. were noted in the questionnaire.

3.3.1.2 Factors affecting outdoor sampling

Meteorology

The meteorological parameters that exhibit greatest influence on the distribution of pollutants are: wind speed and direction, atmospheric stability, and precipitation (Altwicker *et al.*, 1999). Wind speed determines the time it takes for the pollutant to be transported from a source to a receptor and accounts for pollutant diffusion in the direction of wind; thus pollutant concentration at any receptor is inversely proportional to the wind speed. However, for particulate matter, an increase in wind speed can lead to an increase in PM concentrations due to resuspension of PM from the ground. Wind direction explains in which direction the pollutant travels and which receptor will be affected (Altwicker *et al.*, 1999).

Atmospheric stability describes the lack of vertical air movement; if an atmosphere is stable vertical air movement is almost non-existent. This occurs when a parcel of air rising is cooler than the surrounding air; it will go down to its original elevation. Downward movement of a parcel of air leads to warming of the parcel thus it will rise back to its original elevation; vertical movement is dampened by adiabatic cooling or warming thus the atmosphere is stable. Conversely, if a parcel of air rising cools slower than the surrounding air, it is accelerated upwards by buoyancy force. Moving downward, the air parcel cools slower and is accelerated downward; vertical air movement and turbulence is possible. An inversion describes an atmospheric condition where the temperature of the ambient air increases with altitude, hence warmer air blankets colder air. These conditions are very stable thus very little vertical air movement exists. Lack of vertical air movement disallows for vertical dispersion of the pollutant. Precipitation can lead to a decrease in PM concentration through washout of particles (particles are scavenged by rain or snow); or rainout (accumulation of small particles during formation of snowflakes or raindrops in clouds) (Altwicker *et al.*, 1999).

Presence of buildings and vegetation

Presence of buildings and vegetation can lead to disturbances in air flow patterns (turbulence), either leading to areas of decreased or increased air flow (Altwicker *et al.*, 1999).

Sampler height.

To take the above factors into consideration, the sampler was placed indoors in the main living area of the house 2 m away from windows, exterior doors, and ventilation registers at a height of 1m, which represents the breathing zone height of a seated person.

Outdoors, the sampler was placed at least 2 m from the building wall, at least 1 m away from trees and shrubs, 5 m away from any exterior vent, and at a height of 1.70 m. The ambient sampler was placed on the roof of the meteorological station at a height of approximately 4 m.

3.4 Sample Analysis

Gravimetric analysis was performed at the Alberta Research Council (ARC), Analytical Chemistry Business Unit, Vegreville, Alberta, according to the procedure outlined in Figure 3.5. Filters were hand delivered to the ARC lab and picked up by the survey researcher to eliminate any possibility of mishandling of filters during transport.

Gravimetric analysis

The net PM mass on a filter is determined by weighing the filter before and after sampling with a micro balance in a temperature and relative humidity controlled environment. Prior to the gravimetric measurement, filters are conditioned for 24 hours at a constant relative humidity of 40±1% and at a constant temperature of 21±3 °C. A polonium 210 (^{210}PO) radioactive source was located within the balance housing to remove electrostatic energy from filters. The minimum readability of the balance is 0.001 mg, the instrumental detection limit for mass collected on filters is 0.004 mg, and the corresponding method detection limit is about 0.02 mg.

Balance calibration is checked in each batch by weighing a standard mass initially, after every ten samples and then finally. A control filter from the Gelman production lot is weighed in duplicate at the beginning and end of the weighing batch. Weight data is transferred to Microsoft Access and corrected for any drift in standard mass or control filter weights. In the event of excessive drift, recalibration of the balance would be performed. Temperature and relative humidity is recorded at the beginning and end of the weighing batch.

Initial weighing will be done to facilitate sampling within a 30 day expiry time. Final weighing will be done in a timely manner after receipt of exposed filters.

Storage and shipment

These filters are stored in petri dishes and labeled with a filter ID. Two extra ID labels are attached to each petri dish for removal and use in the field on samplers and log sheets.

Petri dishes containing filters are packed in lots of five into a plastic bag, which is placed in a one-cup size screw-top plastic container. The top of the plastic bag is twisted shut and wrapped around the petri dishes to minimize movement during shipment. The screw-top plastic container tops are securely tightened.

Three screw-top plastic containers are placed inside a large, wide-mouthed, plastic canister and sealed securely with a latch hook. When shipped, this canister must always contain three screw-top containers (even if some are empty) to restrict movement.

Two canisters, with packing material, are shipped in a shipping container such as a plastic cooler. One canister may be shipped alone if it is packed securely to restrict movement. The shipping container is labeled to remind handlers that it is to be kept upright at all times.

Exposed filters are stored at 4°C prior to conditioning and after weighing.

University of Alberta project staff will provide transportation between ARC Vegreville and the field site.

Data reporting

Results are reported in a Microsoft Excel format

Figure 3.5: Protocol for gravimetric analysis
(Wharmby, 2000).

3.5 *Air Exchange*

Air exchange can be defined as the exchange of indoor air with outdoor air in a building. The metric for air exchange is air changes/hour (ACH) relating to the building volume, or m^3/h. Air exchange is governed by the leakage of the building structure and mechanical and natural ventilation. Leakage can occur through cracks in the building envelope. The process is driven by pressure differences between the indoor and outdoor environment. Mechanical ventilation is the forced movement of air between the indoor and outdoor environment through fans, whereas natural ventilation occurs through window and door openings and is induced by pressure differences between the indoor and outdoor environment (Health Canada, 1989; Kulmala *et al.*, 1999; U.S. EPA, 1991). Pressure differences are generally higher during the cold months of the year due to greater temperature differences between the indoor and outdoor environment. Other factors affecting air exchange are meteorology (wind, humidity), and habits of the building occupants, i.e. frequency and duration of opening of windows and doors, and operation of fans.

Air exchange rates are important regarding the determination of the impact of outdoor concentrations of the pollutant on indoor concentrations. Further, it is a significant parameter when assessing the relationship between sources and resulting pollutant concentrations (Walsh *et al.*, 1984).

A perfluorotracer (PFT) was used to determine air exchange rates in the homes. It involved the constant release of perfluoromethylcyclohexane (PMCH), while simultaneously sampling for the tracer on a sorbent. The source emits the tracer at a known constant rate over a period of time, while the sorbent – a capillary absorption tube complex, CAT – absorbs the gas at a rate proportional to its concentration (Weker, 1999).

While it would have been ideal to deploy the sources 24 hours prior to sampling begin, the additional visit required to do so was deemed to be too great an inconvenience to the study participants, thus sources were deployed on the same day as the sampler.

Three PFT source were placed in each home during the first visit. The sources were placed in locations that allowed for even distribution of the tracer at heights ranging from 0.5 m to 1.8 m at least 2 m apart. Since the permeation rate is temperature dependent, sources were placed away from heat sources such as lights and appliances and the indoor maximum and minimum temperature for each house was to be determined (Weker, 1999). During the second visit (24 hours after Visit 1) two CATs were deployed in each household approximately 1-1.7m above the ground. CATs and sources were collected 96 hours after the deployment of the sources (Visit 3). Please refer to Appendix C for the detailed air exchange protocol used in the field.

3.6 Meteorological Data

During the sampling period daily atmospheric pressure, temperature, wind speed and direction, and relative humidity were obtained from Environment Canada. For subsequent data analysis a more complete data set for temperature, relative humidity and wind speed and direction was obtained from the WBEA Ft. McKay monitoring station. Reliable precipitation data could not be obtained either from the WBEA Ft. McKay site (Swaine, 2000), nor the Environment Canada Mildred Lake site (Dixon, 2000).

3.7 Field Monitoring Schedule

Sample collection was scheduled to begin in Ft. McKay, Alberta, during the fourth week of September 1999. Thirty households were to be monitored for 24 hours each. During each monitoring period, an indoor PM_{10} sample was collected in the main living area. An outdoor sample was to be collected outside the home, however, outdoor sampling was abandoned after an outdoor sampler was vandalized on Day 1; instead ambient PM_{10} samples were collected at the WBEA meteorological station. A perfluorotracer was released into the home for 96 hours, and CAT's were deployed for 72 hours. A minimum/maximum temperature of the indoor sampling location was obtained for the first 24 hours.

The second round of sampling commenced during the third week of January, 2000. Indoor 24-hour PM_{10} samples were obtained for the same thirty households. Outdoor PM_{10} samples were collected at representative outdoor locations in town, and ambient PM_{10} samples were collected at the WBEA Ft. McKay meteorological station. Three visits were scheduled over a 96-hour period to each home. Appointments were generally scheduled between 16:00 h and 20:00 h. Scheduled appointments were to be reconfirmed by the field staff 24 hours prior to the first appointment.

Upon arrival at the home during the first visit (Visit 1), the study participant was familiarized with the sampling procedure and any existing questions were answered. The home was surveyed for an appropriate PM sampler location and locations for the PFT sources. One sampler was placed inside the home in the main living area, 3 PFT sources and a Min/Max Thermometer where placed throughout the home, one sampler was placed outdoors, and Questionnaire 1 was completed. A map of the layout of the house was drawn, indicating the location of the samplers and PFT sources, Figure 3.6 and Figure 3.7 give a detailed overview of the particulate matter and air exchange sampling protocols.

A. Preseparator / Filter Holder Assembly

Clean and Grease Impactor
Clean every seventh sample or sooner if impactor is heavily soiled.
See **page 53** in MiniVol manual for cleaning

Installing Filters
Place filter cassette in Cassette shoe and remove top ring
Using Teflon forceps, place drain disk on grid
Select a filter and remove cover from petri slide.
Inspect filter for pinholes, cracks etc
Using forceps, remove filter from slide and place on drain disk.
Handle only the edge of the filter
Replace the top ring and place in filter holder
Screw down preseparator adapter
Place filter ID label on the preseparator adapter
Place second filter ID on **Field Data Log** assigning appropriate Sample Type.
Place a clean plastic bag over the top of the Preseparator Adapter Inlet and push the rain cap over the bag.Place the entire assembly into a clean plastic bag and place inside the Grey Thermos box
Keep filter assembly in a vertical position until installed on the sampler
Fill out chain of custody form, and make note of associated filter ID's

Determine Flow Rate
Obtain weather data and note Temperature, Pressure, Wind speed and direction, rel. humidity, on the **Field Data Log**
Phone No: 743 3868
Calculate the Flow setting (see **page 72** in the MiniVol manual or spreadsheet on labtop)
Note required flow on **Field Data Log** under **Start : Roto Flow**

B Sampler Assembly
Check sampler for cracks, tubing integrity, loose connectors
Affix charged battery to sampler
Note battery and sampler ID on **Field Data Log** assigning Sampler to Sample Type
Affix Filter assembly with test filter and drain disk to sampler
Perform leak check by placing hand over inlet while sampler is running (pg. 88)
Set the desired flow rate
Record the **Elapsed Time** on the **Field Data Log**
Remove Filter Assembly and place test filter and drain disk in petri dish

Figure 3.6: Protocol for PM_{10} sampling at Ft. McKay, Alberta

D. Sampler Deployment

Transport MiniVol to sampling site
Select Sampler location
indoors : place sampler on stool (2m from windows & exterior walls)
outdoors: set up tri-pod and anchor (5 m from major vent, 2 m from wall , 1m from trees)
ambient: affix mounting bracket on south roof railing of met station
Set timer
Remove plastic bags from Filter Holder Assembly and attach to Sampler
Crosscheck Sampler ID with assigned sample type and filter ID
Double check set flow-rate
Set Sampler on stool (indoor) or in mounting bracket (outdoor) and lock

E Sampler Retrieval

Remove the sampler from the mounting cradle and set on a firm surface
Lift pump assembly out
Check the sampler face plate for error conditions (page 33)
Verify time and day on LCD
Record elapsed time on **Field Data Log** sheet
Crosscheck Sample type with sampler ID, and filter ID
Obtain ending flow rate:
- press on/auto/off button twice to start the pump and record the flowrate to the nearest 10th of l/min (read at center of the ball)
– if flow meter indicates zero or very low reading, check the quick disconnect to be sure the filter assembly is completely connected.

Press the on/auto/off button twice to stop the pump, record final flow rate in **Field Data Log**
Crosscheck filter number with number recorded on **Field Data Log**
Remove the filter holder assembly, attach plastic bag over inlet, securing with rain cap, bag the whole filter holder assembly and set in Grey thermos box.
The filter holder assembly has to remain vertical at all times!

F Filter Retrieval

Transport Filter Holder Assembly to the Lab
Locate appropriate petri slides
Remove plastic bags from Filter assembly and inlet
Remove preseparator adapter
Inspect filter for pinholes, cracks etc, make note of visible local concentrations of deposits on filter or other irregularities
Remove filter cassette and place in cassette shoe. Remove top ring.
Using forceps, remove filter from filter holder and place in petri dish. Discard drain disk.
Handle only the edge of the filter. Keep filter horizontal at all times.
Cap petri dish and place in transport container, then in sealed glass jar and cooler
Remove the old ID Tag from Filter Holder Assembly place on **Chain of Custody Form** and fill out remainder of Chain of Custody Form

G. Post-sample Sampler Prep

Charge battery
Check inlet and clean and regrease (4 drops !) if necessary

Figure 3.6 : Protocol for PM$_{10}$ sampling at Ft. McKay, Alberta (continued)

Air Exchange Protocol

Numbers of Sources and CATs
General rule of thumb: 1 source per 46 m^2.
for small or tight homes 2 sources; for older, leaky homes: 4-5 sources
2 CATs per home, smaller homes can use 1 CAT

Shipping and Storage
Sources and CATs to be shipped separately
Store Sources in Fort McKay office, exposed and unexposed CATs in trailer in Fort McMurray
CATs to be shipped in ziploc bags, with 4 CATs and a piece of charcoal paper per bag

Deployment of Sources
Deploy sources 24 hours before deploying CATs
Sources are 22 mm bullet aluminum bullet shells inside a 1" x 1/2" x 1/2" block of polyurethane foam; foam and shell are numbered
Place in locations allowing even dispersion of tracer throughout the house; away from vertical thermals (e.g. stairways), heat sources such as lights, appliances
Sources can be suspended, or placed on a flat surface
Note numbers, location, and time and date of deployment of source on AEX form
Deploy min/max thermometer

Deployment of CATs
CATs should be suspended with the open end facing downward (preferred) or placed horizontally on a flat surface with the open end overhanging the edge
Activate CATs by removing the cap adjacent to the ID number (usually black)
Place away from vertical walls, fans, open windows and doors no nearer than 2 m to a source

Pickup/Removal of CATS Sources
Remove CATs and sources separately, CATs first, then sources
Recap CATs and place in sealable plastic bag with carbon paper
Note time and date of removal on AEX form
Transport in separate vehicles; alternatively sources in trunk and CATs in cabin of vehicle

Blanks and Duplicates
10% of samples should blanks, and 10% should be duplicates
Duplicates are placed identically to the main CAT; 3-6 inches from main CAT
Blanks are taken to the sampling location, uncapped, immediately recapped, returned to the plastic bag (with charcoal paper), and left at the house with the main CAT

Figure 3.7: Protocol for air exchange determination at Ft. McKay, Alberta.

The participant was informed that questions about the activities in and around the home would be asked at the next two visits. The appointments for the next two visits were reconfirmed. The outdoor sampler was then deployed. After deployment of all indoor and outdoor samplers, the ambient sampler was deployed at the meteorological station. Approximately 24 hours later (Visit 2) the indoor and outdoor samplers, and the thermometer were retrieved, two CATS were deployed and Questionnaire 2 was completed. The appointment for Visit 3 was reconfirmed. Then the ambient sampler was retrieved at the meteorological station.

During Visit 3 (96 hours after initial sampler deployment) CATS and PFT sources were removed from the home and Questionnaire 3 was completed. The participants were thanked for their time and effort and reminded that a second round of sampling would take place in January of 2000.

3.8 Quality Assurance and Quality Control (QA/QC)

Quality assurance ensures that the sampling and analysis procedures are verified and documented so that uncertainties in the data can be controlled and quantified. During this study various tools were used to ensure that errors were controlled to tolerable levels. Kulkarni *et al.* (1996) ascribe errors occurring during sampling data collection to:

- misinterpretation of sampling plans,
- incorrect implementation of sampling plans with validated protocols,
- disregard for or misunderstanding of the importance of adhering to sampling procedures,
- equipment calibration errors,

- contamination,
- sample storage and transportation errors, and
- sample documentation errors, including sample identification and chain of custody (Kulkarni *et al.*, 1996).

Data quality indicators that describe the performance characteristics of a data set are: precision, bias, representativeness, completeness and comparability (Kulkarni *et al.*, 1996). Kulkarni *et al.* (1996) define precision as the degree of variation between individual measurements of the same property. It is usually expressed as the statistical variance in a data set (Kulkarni *et al.*, 1996). Bias is the systematic error in a measurement in one direction. Representativeness is defined as the degree to which the data accurately represents the variable of interest. It is usually evaluated in qualitative terms, and requires judgment as to the appropriate use of a sampling strategy, proper randomization and adequate sample numbers. Completeness relates the number of samples planned to the number of samples successfully collected. Comparability refers to the comparability of the data set with other similar studies. It can be ensured by using sampling protocols that are comparable to sampling protocols used in similar studies (Keith, 1996; Kulkarni *et al.*, 1996).

This study addressed the above mentioned issues by having the study design reviewed by a statistician, by comparing the prepared sampling protocols with sampling protocols of existing similar studies, by ensuring that the same personnel that designed the study and sampling protocol executed the field work, and by using blanks and collocated samples.

Various types of blanks were used to assess the quality of the sampling, filter handling, and analysis procedures. Black (1996) suggested as a general rule the use of 5-10% of the analysis to be blanks.

Field blanks were used to measure background contamination due to handling of the filters. Pre-weighed filters were loaded into the sampling head, transported to sampling site, installed onto the MiniVol, immediately taken off, returned to the lab, unloaded into a petri-dish, returned to the sampling site and left with the sampler for the 24 h sampling period. *Blind blanks* were submitted to the gravimetric analysis laboratory to assess the analyst's and laboratory's proficiency. The pre-weighed filter was returned to the laboratory without having been removed from the petri dish. *Trip blanks* were used to identify contamination problems due to transport. Pre-weighed filters were returned to the lab without having been removed from the petri dish or the transport container. *Collocated/Replicate samples* were used to estimate overall precision, two MiniVol samplers were used side by side at indoor, outdoor and/or ambient locations whenever scheduling permitted. All samplers were calibrated prior to each sampling period using a Wet Test meter (GCA/Precision Scientific, Chicago, ILL.).

3.9 Changes in Protocol

The sampling schedule was abandoned early in the fall sampling period due to participants being unable to adhere to scheduled times. A routine was established, whereby the field coordinator determined the availability of participants on the same morning of the sampling day and again in the afternoon shortly before sampling began via telephone calls or by trying to locate participants at neighbours/friends homes, stores, at work etc. While this is a somewhat unusual method, it proved highly effective and the research team was able to complete all sampling within the planned timeframe. This led to varying amount of indoor samplers deployed each day ranging from one to three per day during the fall sampling period. During the winter sampling period the same scheduling method was employed with an improved number of 2-3 indoor samplers deployed each day.

Indoor sampling times occasionally had to be shortened due to participants not being able to be home for sampler retrieval. The average sampling time was 23 hours for the fall and winter sampling periods.

Practical limitations required that some compromises be made with the indoor placement of samplers. Placement 2 m away from exterior walls, doors, vents etc would have often meant placement of the sampler in the middle of the main living room. This was not only impractical for the residents of the house, but also simply unacceptable to most of them. Further, the presence of small children often required placement of the sampler in a less visible and accessible location to prevent injury to children or damage to the sampler. Thus, while striving to maintain ideal sampler placement, physical surroundings and participant preferences often dictated a somewhat less ideal location. Generally, the sampler was placed in the main living area, away from vents and doors, and at a height of 1m. However, proximity to windows and/or exterior walls had to be permitted on several occasions.

During the winter sampling several sampler failures occurred at temperatures as high as –15°C. During the winter sampling the outdoor and ambient sampler was left plugged in as it was expected that the battery would not last for 24 hours in below 0°C temperatures. Battery voltages were still at approximately 12V after the samplers had failed, thus indicating that either another component led to sampler failure or the battery was simply not able to deliver the required current to run the sampler when it cooled off. It was further observed that transporting the sampler from a cold to a warm environment caused condensation to form on the inside of the sampler. Subsequent exposure of the sampler to a cold environment led to freeze up of the orifice on one occasion, which led to a low flow shut down. Consequently, outdoor and ambient samplers were not brought into the warm vehicle, but rather transported in the back of a pick-up truck. After several outdoor/ambient sampler failures, it was decided to construct an "incubator" for the MiniVol to avoid further sample loss. Two insulated food coolers were modified to accommodate the sampler and a battery (see Figure 3.8).

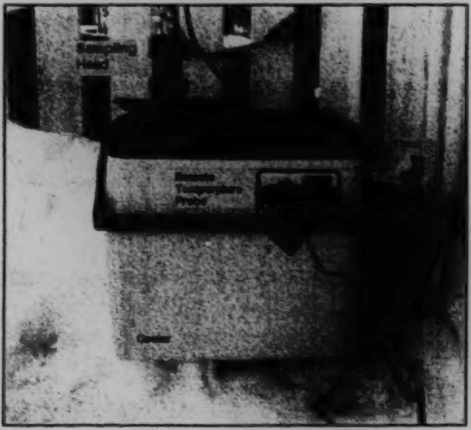

Figure 3.8 MiniVol air sampler set up for winter outdoor sampling.

The coolers were equipped with an automotive battery heat blanket (80W), a timer to cycle the heater on and off, and a remote temperature probe to monitor the temperature inside the cooler. The whole assembly could be hung onto the tri-pod bracket. Two 24-hour tests were run, the on/off cycling of the heater was adjusted to ensure that the MiniVols would not overheat ($T < 40$ °C), and the unit was then deployed in the field. Only one outdoor sampler failure occurred due to a tripped breaker at the meteorological station after implementing the use of the MiniVol "incubator".

4 Results and Discussion

All samples were collected and analyzed according to the protocols outlined in Materials and Methods. The data available for analysis were:

- PM_{10} data (fall and winter) - indoor, ambient,
- PM_{10} data (winter) – outdoor,
- air exchange data (fall),
- meteorological data (fall and winter), and
- questionnaire data (fall and winter).

The focus of the analysis was on the PM_{10} data as it supports the initial objectives of the study – to estimate the indoor and outdoor PM_{10} concentration distributions for the target population of households in Ft. McKay, Alberta. Air exchange, and questionnaire data were primarily collected to assist in the explanation of results.

4.1.1 Quality Assurance/Quality Control

A variety of QC tools were utilized to ensure high quality data and the usability of the collected PM samples for data analysis. Blank filters were used to measure background contamination due to handling; collocated samples were collected to measure sampling and analysis. The analytical Method Detection Limit, MDL, was determined experimentally by the ARC Gravimetric Analysis Laboratory (Vegreville, Alberta).

4.1.2 Availability and Quality of data

Summarized in Table 4-1 is the availability of the PM_{10} data for the fall of 1999 and winter of 2000 sampling periods. Rows correspond to the various sample types for which PM_{10} data were collected. Each row gives the number of samples usable and unusable, the number of samples processed, and the percentage usable. The sample collection efficiency for most sample types was above 90% with the exception of the Fall Outdoor samples due to vandalizing of the sampler (and subsequent complete abandoning of outdoor sampling), and the Winter Ambient and/or Outdoor samples due to sampler failures caused by extreme cold temperatures.

Table 4-1: Summary of the availability of 24-hour PM_{10} samples for further data analysis.

SAMPLE TYPE	USABLE	UNUSABLE	TOTAL	PERCENT USABLE
Fall 1999				
Indoor	35	1^a	36	97%
Outdoor	3	1^b	4	67%
Ambient	22	2^c	24	92%
Blanks	22	-	22	100%
Winter 2000				
Indoor	37	2^a	39	95%
Outdoor	20	$2^{c,d}$	22	91%
Ambient	12	5^c	17	70%
Blanks	21	-	21	100%

[a] Programming error, [b] Sampler vandalized, [c] Sampler failure, [d] failed leak check

4.1.3 Blanks

Various types of blank filters were used to evaluate problems due to filter handling. Field blanks were used to identify contamination problems due to loading and unloading procedures of filters into the sampling head of the MiniVol. Field blanks were pre-weighed filters, loaded into sampling head, double-bagged, transported to the sampling site, installed on the MiniVol sampler, taken off, returned to the lab, unloaded into the petri dish, returned to the sampling site and left with the sampler for the 24 h sampling period. Field blanks were collected once a week for each sampler deployed on that day. Trip blanks were utilized to identify contamination problems due transport. Pre-weighed filters were returned to the lab without having been removed from the petri dish. Blind blanks were used to check the gravimetric laboratory procedures; pre-weighed filters were returned to the lab without having been removed from the petri dish.

The number and types of blanks collected, and the gravimetric results for blank filters are given in Table 4-2:

Table 4-2: Gravimetric results for blank filters.

	FIELD BLANKS	TRIP BLANKS	BLIND BLANKS
Fall 1999			
# of filters	14	6	2
Range of Weights for exposed filters [μg]			
Minimum	< 4 (MDL = 20)	< 4 (MDL = 20)	< 4 (MDL = 20)
Maximum	12 (MDL = 20)	9 (MDL = 20)	< 4 (MDL = 20)
Winter 2000			
# of filters	12	4	5
Range of Weights for exposed filters [μg]			
Minimum	< 4 (MDL = 20)	< 4 (MDL = 20)	< 4 (MDL = 20)
Maximum	8 (MDL = 20)	< 4 (MDL = 20)	< 4 (MDL = 20)

All blank filter weights were below detection, thus indicating that filter contamination due to handling was very small or not present at all.

4.1.4 Precision

In order to characterize the precision of the MiniVol Sampler PM_{10} measurement method, collocated samples were collected periodically. It was attempted to obtain a minimum of 10% collocated samples per sampling round. This goal was not met in the fall of 1999 due to scheduling difficulties, which resulted in lack of samplers available to obtain the 10% collocated measurements. During the Winter 2000 sampling period the 10% target was met.

Relative Standard Deviations (RSD) of particulate concentrations were calculated for each pair:

$$RSD = \frac{RPD}{\sqrt{2}} \qquad \textbf{Equation 3}$$

$$RPD = 100\frac{(X1 - X2)}{\left(\frac{(X1 + X2)}{2}\right)} \qquad \textbf{Equation 4}$$

RSD = relative standard deviation
RPD = relative percent difference
X1, X2 = the two observed concentrations

The summary of results is given in Table 4-3. Refer to Appendix E for detailed results. The number of pairs from which the relative standard deviations were calculated, the mean, median, maximum, and standard deviation for each sample type are given in Table 4-3.

Overall precision was good, the quality assurance objective (QAO) for precision of 10% mean relative standard deviation was met.

Table 4-3: Relative standard deviation [%] calculated from collocated PM$_{10}$ concentration data.

SAMPLE TYPE	# OF REPLICATES	MEAN RSD [%]	MAXIMUM [%]	PERCENTILES				STD. DEV. [%]
				25	50	75	90	
Amb./Out	7	9	27.9	2.1	6.7	12	20.9	9.6
Indoor	10	9.3	28.8	2.8	6.0	8.9	27.0	10.1

From Figure 4.1, it can be observed that the precision of the MiniVol decreased with decreasing concentrations of particulate matter. This trend is in line with findings of others (AirMetrics, 1998,Anon, 2000a).

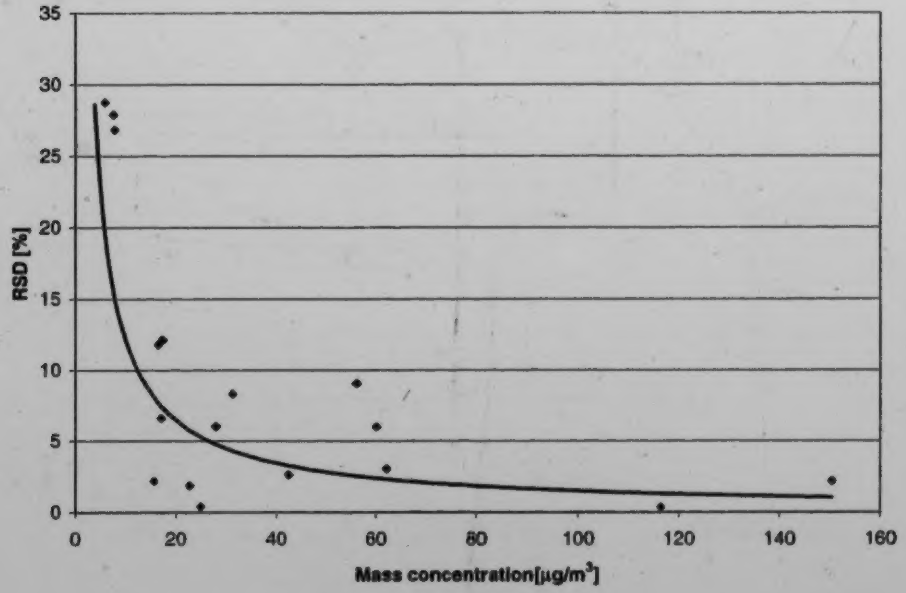

Figure 4.1: Precision of MiniVol PM$_{10}$ mass concentrations [μg/m^3] as function of RSD [%].

4.2 Fall Sampling

Fall sampling commenced on September 22, and ended on October 21, 1999. A total of 86 PM_{10} samples, including blanks and replicates were deployed; 28 air exchange measurements, and 28 indoor temperature measurements were obtained. Indoor samples were collected in 30 residences in the community of Ft. McKay, ambient samples were collected at the WBEA Ft. McKay Meteorological Station.

4.2.1 Fall Meteorology

Data for ambient temperature, wind speed and direction, and relative humidity, were obtained from the Wood Buffalo Environmental Association Ft. McKay Monitoring Station. The hourly data were averaged over 24 hours starting at 16:00 hours, as this time approximately corresponded to the start of the 24-hour sampling period. The data for atmospheric pressure were obtained daily via telephone from Environment Canada, Ft. McMurray airport station at the beginning and end of each sampling period. Table 4-4 lists the average ambient temperature, relative humidity, atmospheric pressure, wind speed and -direction for the fall sampling period. The average temperature for the fall sampling period was 3.8°C, average relative humidity was 68.9%, average atmospheric pressure was 101.3 kPa, and average wind speed for the sampling period was 9 km/h.

Table 4-4: Summary of average meteorological parameters for the fall sampling period at Ft. McKay, Alberta.
^{a}WBEA monitoring station, ^{b} Environment Canada, Ft.McMurray airport station

	24-HOUR AVERAGE	MINIMUM	MAXIMUM
Temperature [°C]^a	3.8	-2.7	15.1
Relative Humidity [%]^a	68.9	42.0	90.0
Atmospheric Pressure [kPa]^b	101.3	99.7	102.9
Windspeed [km/h]^a	9	1	32

Figure 4.2 and Figure 4.3 provide an overview of daily ambient temperature fluctuations and daily R.H. levels. It can be seen from these figures that the ambient temperature and R.H. experienced large fluctuations during the sampling period.

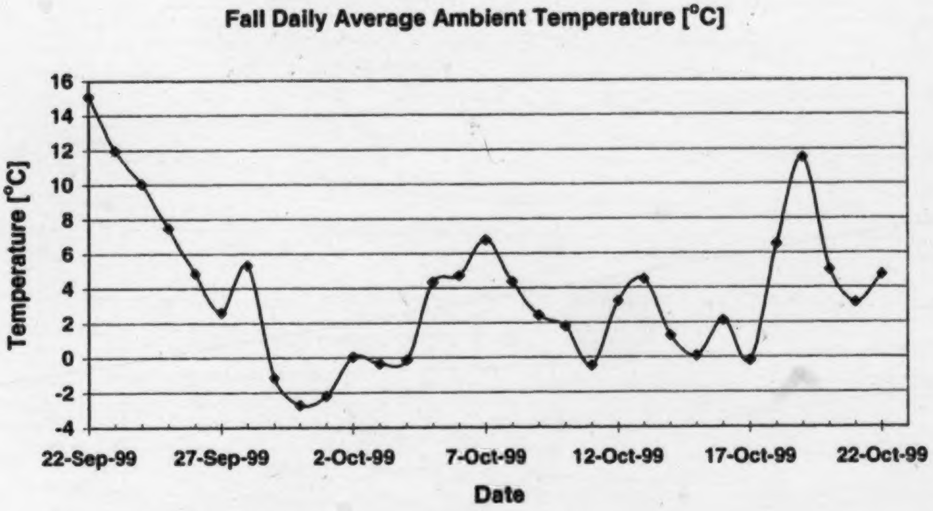

Figure 4.2: Fall 24-hour average daily temperature at Ft. McKay [°C]

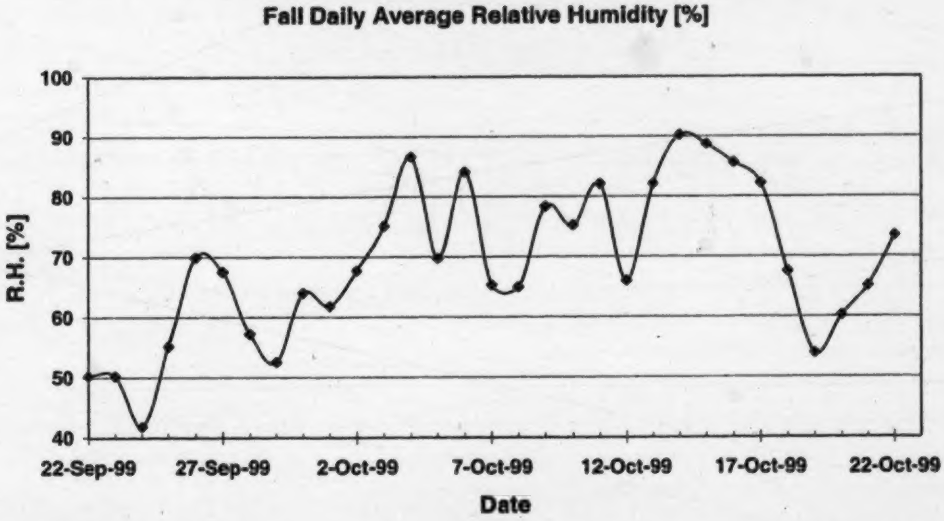

Figure 4.3: Fall 24-hour average daily relative humidity at Ft. McKay [%]

Wind speed and direction for the fall sampling period are presented in Figure 4.4. Average wind speed for the sampling period was 9 km/h with speeds being predominantly in the 6-11 km/h range, prevailing from a southerly direction approximately 50% during the fall sampling period.

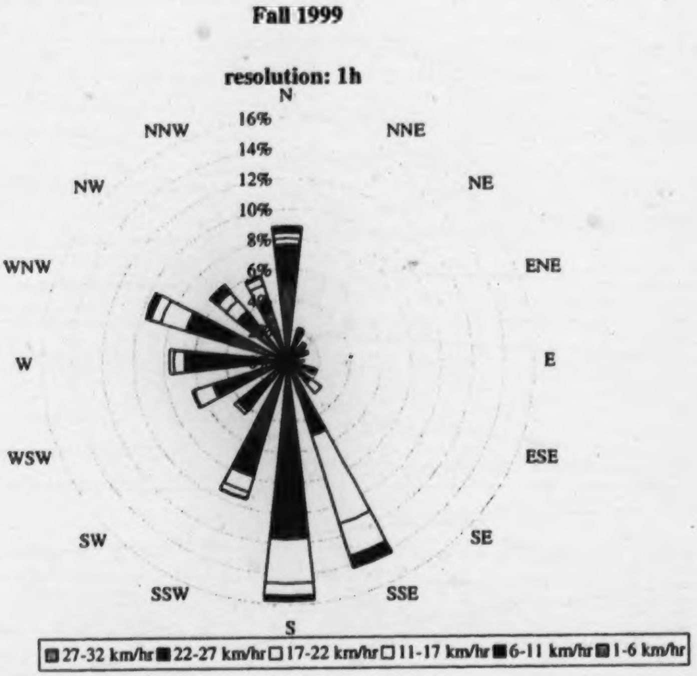

Figure 4.4: Wind speed and direction at the WBEA Ft. McKay meteorological station during the fall 1999 sampling period.

Since the current oil sands operations are predominantly located south, south-east, and south-west of Ft. McKay, and prevailing winds were from southerly directions, Ft. McKay should have experienced impacts from these industries during the sampling period.

4.2.2 Air Exchange

Valid air exchange measurements were obtained for 17 houses and 7 manufactured homes. Samples were analysed by the Harvard School of Public Health. Six samples were lost in the field. Replicates were obtained to estimate the precision of the method. The relative standard deviation for the replicates ranged from 0% to 7.5% with a mean RSD of 2.7%. Additionally, 10% of blanks were deployed. Refer to Appendix C for the methodology and results.

The results for air exchange measurements are given in Table 4-5 in air changes per hour (ACH). Air exchange rates ranged from 0.15 to 0.73 ACH with an average air exchange rate of 0.39 ACH. With the low air exchange rates observed it can be concluded, that particulate generated indoors had long air residence times allowing for accumulation of particles from indoor sources.

Table 4-5: Summary of results for air exchange measurements in 24 residences at Ft. McKay, Alberta, during the fall of 1999.

	AIR EXCHANGE RATE [ACH]
N (sample size)	24
Mean [μg/m^3]	0.39
Minimum [μg/m^3]	0.15
Maximum [μg/m^3]	0.73
Geometric Mean [μg/m^3]	0.35
Standard Deviation	0.17
Percentiles [μg/m^3]	
10th	0.20
25th	0.23
50th	0.37
75th	0.50
90th	0.58

Air exchange rates observed here are comparable to findings of other studies. Jones (1999) found that newer homes have air exchange rates ranging from 0.2-0.3 ACH (Jones, 1999). The majority of homes (66%) studied in Ft. McKay were built in the past 20 years, thus air exchange rates observed are comparable to these findings. Pellizari et al. (1992) reported an average of 0.76 ACH in Riverside, California (Pellizari *et al.*, 1992). Abt *et al.* (2000) conducted a study in the metropolitan Boston area, air exchange rates ranged from 0.12 to 24.3 ACH. The higher air exchange rates were observed during the summer, when doors and windows were kept open. The winter mean air exchange rate observed was 0.72 ACH (Abt *et al.*, 2000).

Mean air exchange rates of houses and manufactured homes were compared using a two-sample t-test. Microsoft Excel was used for all statistical calculations. There was no statistical difference in mean air exchange rates of houses and manufactured homes ($t_{stat} = 0.39$, $t_{0.025(2)24} = 2.39$, $p=0.7$).

4.2.3 Indoor Temperatures

Indoor temperatures were obtained with a min/max thermometer for 24 of the 30 residences. Data from six residences was not obtained due to insufficient equipment availability and equipment malfunctioning. The mean indoor average temperature was 20.4 °C, minimum observed average temperature was 17 °C and maximum observed average temperature was 24.3 °C.

4.2.4 Fall PM_{10} Results

The primary objective of this study was to estimate the potential exposure of the residents of Ft. McKay to PM_{10}. To assess exposure, indoor and ambient 24-hour measurements were taken. The 24-hour concentrations were calculated as time-weighted averages across the 24-hour measurement period. Below detection data was set to one half the method detection limit (1.5 μg/m^3) for data analysis purposes. Replicates were averaged. Refer to Appendix D for the descriptions of equations used to calculate the 24-hour time-weighted average concentrations.

Table 4-6 provides the distribution of the 24-hour PM_{10} concentrations at the ambient and indoor sample locations. Ambient PM_{10} concentrations ranged from 1.5 to 20.5 μg/m^3, the mean ambient PM_{10} concentration was 6.2 μg/m^3. Indoor PM_{10} concentrations ranged from 6.2 to 212 μg/m^3, with a mean indoor PM_{10} concentration of 83.4 μg/m^3.

Table 4-6: Summary of results for fall indoor and ambient PM_{10} measurements at Ft. McKay, Alberta.

	AMBIENT [RSD ±9%]	INDOOR [RSD ±9.3%]
N	20	29
Mean [μg/m^3]	6.2	83.4
Minimum [μg/m^3]	1.5	6.2
Maximum [μg/m^3]	20.5	212
Geometric Mean [μg/m^3]	4.7	62.3
Standard Deviation	5.1	54.8
Percentiles [μg/m^3]		
10th	2.2	24.2
25th	3.0	38.3
50th	4.7	77.1
75th	7.6	132
90th	12.9	148

From the standard deviation in Table 4-6 it can be seen that indoor concentrations are highly variable compared to ambient PM_{10} concentrations, thus indicating that indoor sources rather than ambient sources have a significant influence on indoor concentrations. Indoor PM_{10} concentrations less than 20 $\mu g/m^3$ for individual homes coincided generally with an absence of smoking in the household and/or the absence of the occupant(s) during the 24-h sampling period.

Indoor and outdoor PM_{10} concentrations are plotted in Figure 4.5. Indoor concentrations of PM_{10} were higher than outdoor concentrations. This is consistent with findings of previous studies (Quackenboss *et al.*, 1989; Abt *et al.*, 2000; Anon, 2000; Jones *et al.*, 2000).

Due to non-existing ambient or residential indoor Canadian PM_{10} standards, results were related to other selected ambient standards. Approximately 13% of the indoor PM_{10} measurements exceeded the U.S. National Ambient Air Quality Standard of 150 $\mu g/m^3$ as 24 hour average and 67% of the indoor measurements exceeded the proposed EU Standard and current California Ambient Air Quality Standard of 50 $\mu g/m^3$. None of the ambient PM_{10} measurements exceeded any of the above standards.

These results indicate that a significant portion of the study population is exposed to particle levels in the indoor environment that exceed U.S. ambient and other proposed or current health-based air quality standards.

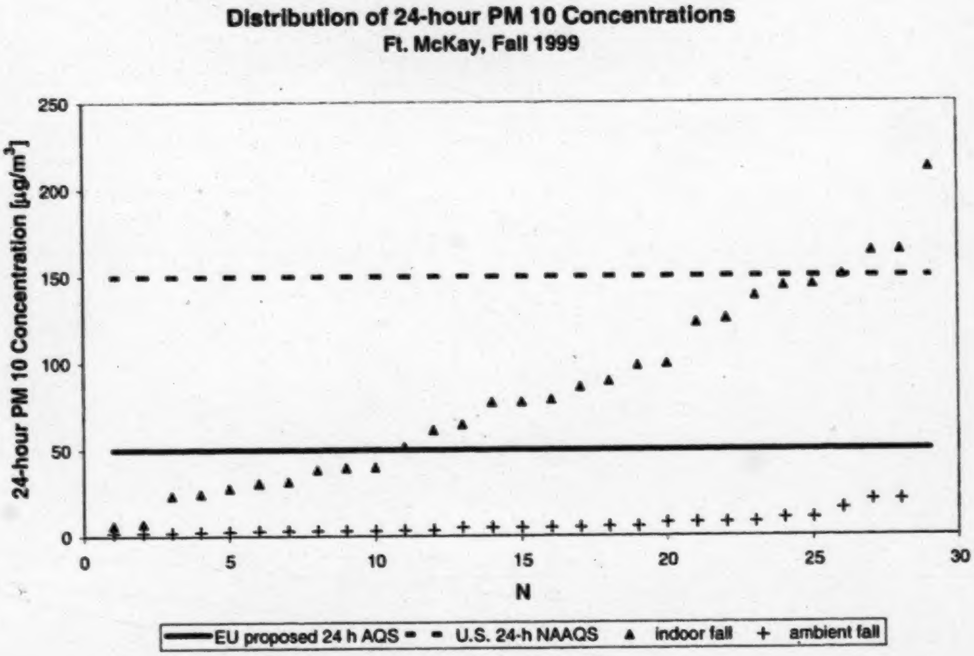

Figure 4.5: Distribution of fall indoor and ambient 24- hour PM_{10} concentrations in relation to selected air quality standards.

Results of previous studies indicate that the actual personal exposure to PM_{10} is likely to be higher than the results obtained from the micro-environmental and ambient measurements. Smokers will have an even higher exposure due to particles directly inhaled. Thus, it becomes evident that a portion of the study population in Ft. McKay is exposed to high particle levels as a result of indoor PM_{10} levels. Indoors is the location where people generally spend most of their time. Further, the results indicate that PM_{10} levels measured during the fall sampling period at the ambient location highly underestimate indoor PM_{10} levels.

4.3 *Winter Sampling*

Winter sampling commenced on January 19, and ended February 3, 2000. A total of 99 PM_{10} samples including blanks and replicates were deployed. No air exchange measurements were obtained due to budgetary restrictions. Indoor samples were collected in 30 residences in the community of Ft. McKay, ambient samples were collected at the WBEA Ft. McKay Meteorological Station, and outdoor samples were collected at representative sites in Ft. McKay (Figure 3.2).

4.3.1 *Winter Meteorology*

Data for ambient temperature, wind speed and direction, and relative humidity were obtained from the Wood Buffalo Environmental Association Ft. McKay Monitoring Station. The hourly data was averaged over 24 hours starting at 16:00 hours, as this time approximately corresponded to the start of the 24-hour sampling period. The data for atmospheric pressure was obtained daily via telephone from Environment Canada, Ft. McMurray airport station at the beginning and end of each sampling period. Table 4-7 lists the average ambient temperature, relative humidity, atmospheric pressure, wind speed and -direction for the winter sampling period.

Table 4-7: Summary of average meteorological parameters for the winter sampling period at Ft. McKay, Alberta.

	24-HOUR AVERAGE	MINIMUM	MAXIMUM
Temperature [^oC]	-14.1	-35.3	-2.0
Relative Humidity [%]	76.1	63.0	85.0
Atmospheric Pressure [kPa]	101.7	101.4	102.4
Windspeed [km/h]	7	0	20

The average temperature for the winter sampling period was -14.1°C, average relative humidity was 76.1%, average atmospheric pressure was 101.7 kPa , and average wind speed for the sampling period was 7 km/h.

Figure 4.6 and Figure 4.7 provide an overview of daily ambient temperature fluctuation and daily R.H. levels. From the graph it can be seen that the ambient temperature remained below 0°C during the entire sampling period and experienced large fluctuations. Relative Humidity stayed above 60% during the entire sampling period.

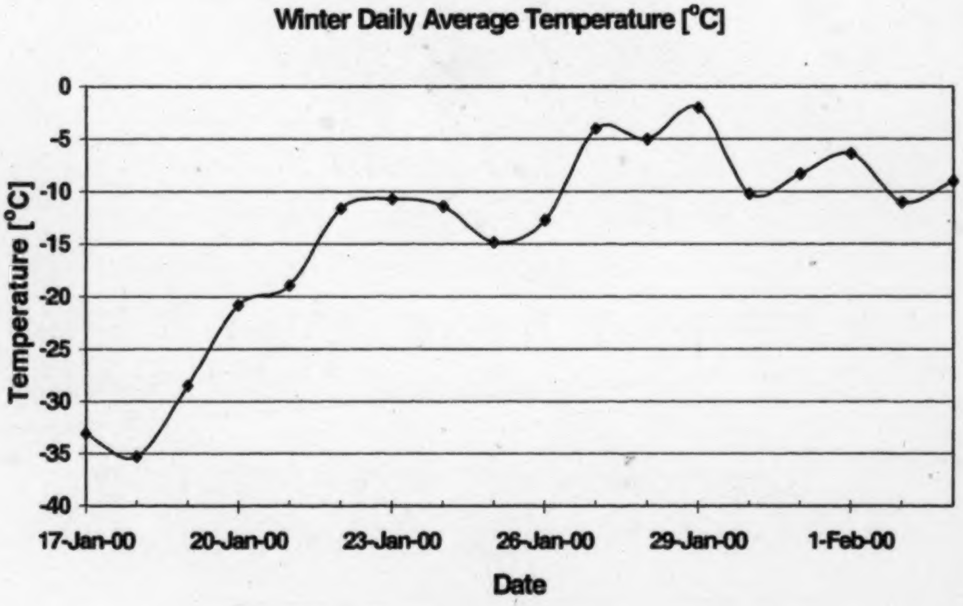

Figure 4.6: Winter daily average temperature [°C]

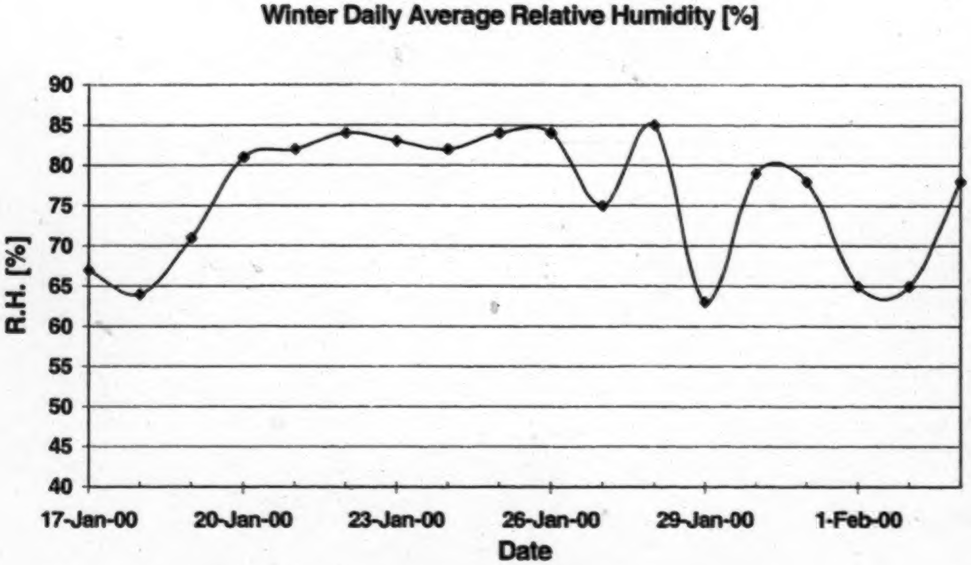

Figure 4.7: Winter daily average relative humidity [%]

Wind speed and direction for the winter sampling period are presented in Figure 4.8. Average wind speed for the sampling period was 7 km/h with speeds being predominantly in the 3-10 km/h range, prevailing from a southerly direction approximately 90 % during the winter sampling period.

Since the current oil sands operations are predominantly located south, south-east, and south-west of Ft. McKay, and prevailing winds were from southerly directions, Ft McKay should have experienced impacts from these industries during the sampling period.

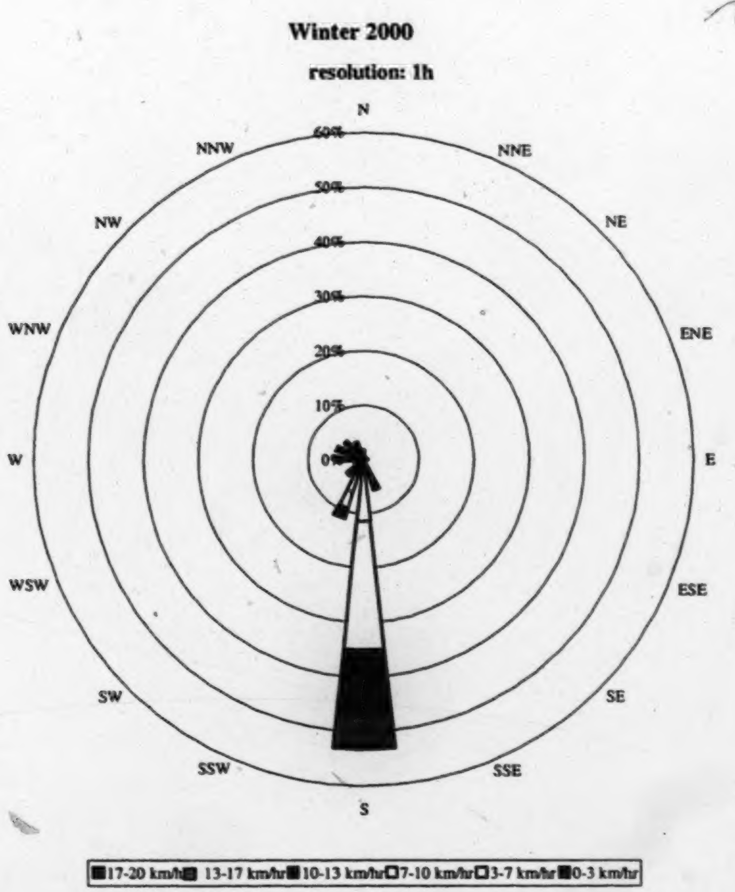

Figure 4.8: Wind speed and direction at the WBEA Ft. McKay meteorological station during the winter 2000 sampling period.

4.3.2 Winter PM $_{10}$ Results

The primary objective of this study was to estimate the potential exposure of the residents of Ft. McKay to PM_{10}. To assess exposure, indoor, outdoor and ambient 24-hour measurements were taken. The 24-hour concentrations were calculated as time-weighted averages across the 24-hour measurement period. Below detection data was set to one half the method detection limit (1.5 $\mu g/m^3$) for data analysis purposes. Replicates were averaged. Refer to Appendix D for description of equations used to calculate the 24-hour time-weighted average concentrations.

Table 4-8 provides the distribution of 24-hour PM_{10} concentrations at the ambient and indoor sample locations. Ambient PM_{10} concentrations ranged from 4.1 to 29.1 μg/m^3, the mean ambient PM_{10} concentration was 16 μg/m^3. Outdoor PM_{10} concentrations ranged from 5.7 to 27.5 μg/m^3, the mean outdoor concentration was 17.4 μg/m^3. Indoor PM_{10} concentrations ranged from 3.4 to 142 μg/m^3, with a mean indoor PM_{10} concentration of 48.4 μg/m^3.

Table 4-8: Summary of results for winter indoor, ambient and outdoor PM_{10} measurements at Ft. McKay, Alberta.

	AMBIENT [RSD ±9%]	OUTDOOR [RSD ±9%]	INDOOR [RSD ±9.3%]
N (sample size)	10	15	29
Mean [μg/m^3]	16	17.4	48.4
Minimum [μg/m^3]	4.1	5.7	3.4
Maximum [μg/m^3]	29.1	27.5	142
Geometric Mean [μg/m^3]	13.2	15.9	34.8
Standard Deviation	9.3	7	36.4
Percentiles [μg/m^3]			
10th	6.7	9.3	9.1
25th	7.1	12.2	22.6
50th	14.2	16.9	41
75th	24.3	23.7	59.1
90th	27.9	26.6	111

From the standard deviation listed in Table 4-8, it can be seen that indoor concentrations are highly variable compared to ambient or outdoor PM_{10} concentrations, thus indicating that indoor sources rather than ambient sources have a significant influence on indoor concentrations. Indoor PM_{10} concentrations less than 20 μg/m^3 for individual homes coincided generally with an absence of smoking in the household and/or the absence of the occupant(s) during the 24-h sampling period.

Indoor and outdoor PM_{10} concentrations are plotted in Figure 4.9. Indoor concentrations of PM_{10} were higher than outdoor/ambient concentrations. Again, this is trend is in line with findings of previous studies (Quackenboss *et al.*, 1989; Abt *et al.*, 2000; Anon, 2000; Jones *et al.*, 2000)

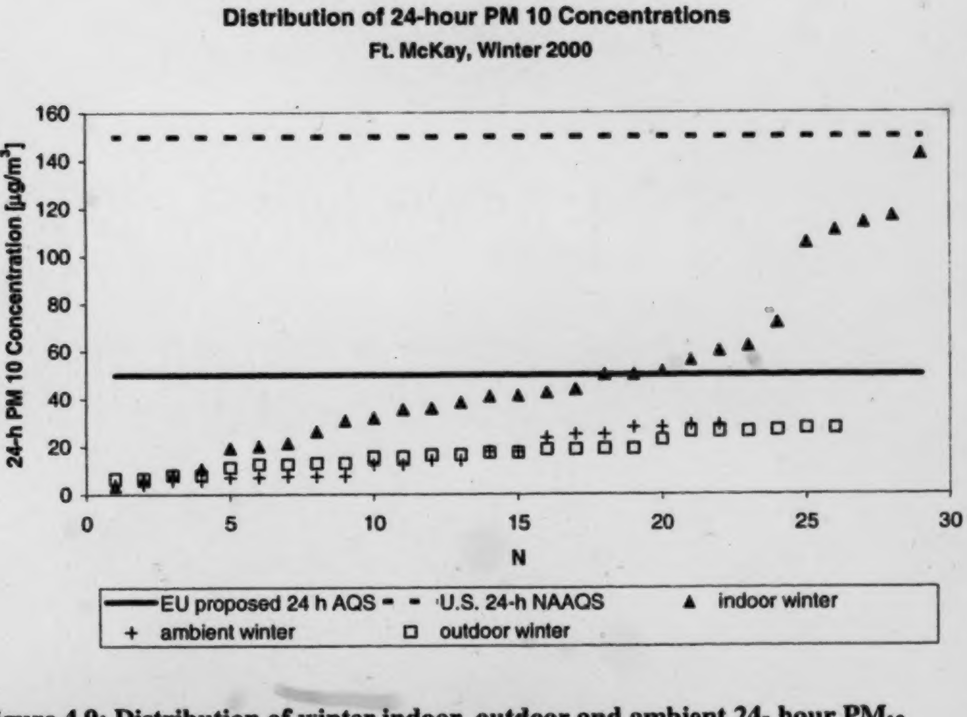

Figure 4.9: Distribution of winter indoor, outdoor and ambient 24- hour PM_{10} concentrations in relation to selected air quality standards.

None of the indoor PM_{10} measurements exceeded the U.S. National Ambient Air Quality Standard of 150 µg/m^3 as 24-hour average. Thirty-eight % of the indoor measurements exceeded the proposed ambient EU Standard and current California Ambient Air Quality Standard of 50 µg/m^3. None of the ambient or outdoor PM_{10} measurements exceeded any of the above standards.

These results indicate that a portion of the study population was exposed to particle levels in the indoor environment that exceed the California and EU ambient standard. Results of previous studies indicate that the actual personal exposure to PM_{10} is likely to be higher than the results obtained from the micro-environmental and ambient measurements. Smokers will have an even higher exposure due to particles directly inhaled. Again, it becomes evident that a portion of the study population in Ft. McKay was exposed to high particle levels in the indoor environment. This is the location where people spend most of their time. Further, the results show that PM_{10} levels measured during the winter sampling period at the ambient/outdoor location highly underestimate indoor PM_{10} levels.

4.4 Associations of Indoor, Outdoor Data with Ambient Data and Meteorological Data

Indoor and outdoor data were matched with the respective ambient data from the same 24-h sampling period. Pearson correlations were generated using Microsoft Excel for the ambient, indoor, and outdoor data for the fall and winter sampling periods. Results are listed in Table 4-9. N refers to the number of sample pairs that could be successfully matched.

Correlations were lowest (0.19) between indoor and ambient measurements during the fall and winter sampling period. Low correlations (0.39) were observed for the outdoor and indoor PM_{10} concentrations. This suggests that indoor PM_{10} levels were not well predicted by outdoor and ambient PM_{10} levels. Highest correlations (0.93) were observed between ambient and outdoor concentrations.

Table 4-9: Correlations of the ambient site, with indoor, and outdoor PM_{10} concentrations.

FALL	Ambient	WINTER	Ambient	Outdoor
Indoor	0.19 N=28	Indoor	0.19 N=21	0.39 N=25
Outdoor	N/a	Outdoor	0.93 N=13	-

High correlations between outdoor and ambient concentrations indicate that PM_{10} measurements obtained at the Ft. McKay WBEA meteorological station were a good representation of the outdoor levels across the community of Ft. McKay during the monitoring period.

Average 24-hour meteorological data were matched with indoor and outdoor/ambient data of the same time period. Pearson correlation coefficients were obtained using Microsoft Excel. Table 4-10 gives correlations between the PM_{10} and the meteorological data. No strong correlations were observed. A moderate correlation (0.43) between ambient PM_{10} concentrations and wind speed was observed during the fall sampling period. During the winter sampling period wind speed and temperature were negatively correlated to PM_{10} concentrations.

Table 4-10: Correlations of meteorological data with PM_{10} data.

FALL	Temperature	R.H.	Wind speed
Indoor PM 10	0.20	-0.03	0.35
Ambient PM 10	0.20	-0.36	0.43
WINTER			
Indoor PM 10 N=29	-0.21	0.12	-0.30
Ambient PM 10 N=12	0.02	-0.29	-0.24
Outdoor PM 10 N=15	-0.25	-0.24	-0.34

4.5 Comparison of Indoor and Outdoor Data

Indoor-outdoor paired PM_{10} concentrations were tested using a paired two-sample t-test for means to determine whether the indoor or outdoor mean concentration was significantly higher. Microsoft Excel was used to calculate the t statistics. For both the fall and winter sampling periods the indoor mean concentrations were found to be significantly higher ($t_{stat\ fall} = 7.8$, $t_{0.05(2)27} = 2.1$, $p= 2.4*10^{-8}$; $t_{stat\ winter} = 4.8$, $t_{0.05(2)24} = 2.1$, $p=5.6*10^{5}$) than the outdoor mean concentrations.

4.6 Indoor to Outdoor Ratios

Indoor to outdoor (I/O) ratios were calculated for the fall and winter sampling periods. The paired mean indoor/outdoor ratio for the fall sampling period was 19.5, range 1.9 to 76.9 (N=29). The paired mean I/O ratio for the winter sampling period was

5.5, range 0.4 to 27.0 (N=22) for the ambient-indoor locations, and 3.3, range 0.3 to 9.0 (N= 26) for the outdoor-indoor locations. The indoor/outdoor ratio is an indicator of whether indoor levels are influenced by significant indoor sources of particulates or if indoor levels are the result of outdoor particle concentrations. If indoor sources were absent, the I/O ratio would be less or equal one.

The I/O ratio obtained for the fall sampling period suggests that significant indoor sources for PM_{10} were present. I/O ratios for the winter sampling period were closer to one than during the fall, however, they are still indicative of strong indoor particle sources. This study did not control for smoking versus non-smoking households, hence the influence of smoking was not examined using these results.

Table 4-11compares I/O ratios from this study with other studies. I/O ratios less than one generally occurred in residences without significant indoor sources i.e. smoking, or where outdoor concentrations were high. Quackenboss *et al.* (1989) determined a median I/O ratio of 0.69 for non-smoking households and a median I/O ratio of 1.2 for households with smoking activity. Colome *et al.* (1992) found that in homes of asthmatics indoor concentrations were consistently lower than outdoor concentrations. It was concluded that this is probably due to asthmatics avoiding potential triggers of asthma attacks such as smoking, pets and cleaning compounds, which can be significant indoor sources of PM. Generally, I/O ratios are highly dependent on indoor activities that lead to the generation and resuspension of particles, as well as particle loss (i.e. through ventilation); it is these processes that cause the indoor concentration to track less closely with the outdoor concentration (Traynor *et al.*, 1985).

Comparison of the indoor and outdoor PM concentrations with those of other studies shows that indoor PM_{10} levels were high, and outdoor PM_{10} levels low. These findings support conclusions drawn by Wallace (1996) that where outdoor concentrations are low, indoor concentrations greatly exceed outdoor concentrations (Wallace, 1996).

Table 4-11: Indoor-outdoor ratios observed in other studies compared to I/O ratios observed in Ft. McKay, Alberta.

REFERENCE	LOCATION	INDOOR MEAN [$\mu g/m^3$]	OUTDOOR MEAN [$\mu g/m^3$]	I/O RATIO[a]
	Ft. McKay, Alberta, Canada	83 48	6.2 16	20 (fall)[b] 5.5 (winter)[b]
(Jones *et al.*, 2000)	Birmingham, United Kingdom	48 35 17 34	24 18 13 14	1.9 2.3 1.3 2.9
	Rural, United Kingdom	27 45 12	17 17 15	1.8 2.7 1.3
(Colome *et al.*, 1992)	Orange County California,USA	43 (3.7)[c]	60.8 (4.7)[c]	0.7
(Pellizari *et al.*, 1992)	Riverside, California,USA	79	91	0.9
(Janssen *et al.*, 1998)	Amsterdam, Netherlands	35 (19-65)[d]	42 (32-51)[d]	0.8
(Anon, 2000)	Ft. Mc Murray Alberta, Canada	15[e]	12[e]	1.2
(Anon, 2000)	Lethbridge, Alberta, Canada	15[e]	16[e]	1.0
(Abt *et al.*, 2000)	Boston, Massachusetts, USA	20 (16)[f]	17 (9.1)[f]	1.2
(Pellizari *et al.*, 1999)	Toronto Ontario, Canada	23	24	1.0

[a] I/O ratios were calculated from reported mean indoor and outdoor concentrations, [b] I/O ratio calculated as mean paired ratio, [c] standard error, [d] range, [e] median, [f] standard deviation

Cheng *et al.* (2000) summarized ambient concentrations of particulate matter observed in Alberta, Canada. Sampling locations were classified as rural remote, rural influenced, rural industrial and urban. Table 4-12 provides a summary of the mean PM_{10}

concentrations reported for these sites. Means were obtained from daily, weekly and annual averages.

Table 4-12: Summary of mean ambient PM_{10} concentrations in Alberta
(after Cheng *et al.*, 2000).

LOCATION	MEAN PM_{10} CONCENTRATIONS [$\mu g/m^3$]
Rural remote	8.8
Rural influenced	17
Rural industrial	35
Urban:	
Edmonton	29
Calgary	26

Comparison of the ambient data from this study with data reported for Alberta sampling sites shows that during the fall sampling period the mean PM_{10} concentrations in Ft. McKay were lower than the mean PM_{10} concentration reported for Alberta rural remote sites. Wintertime mean PM_{10} concentrations in Ft. McKay are comparable to the reported rural influenced site levels (Table 4-12) but well below reported rural industrial and urban sites in Alberta.

4.7 Seasonal Variation

Fall and winter ambient and indoor data were compared to determine whether PM_{10} concentrations exhibited seasonal variation. Results from a two-sample t-test revealed that there was a statistically significant difference between fall and winter ambient PM_{10} concentrations ($t_{stat} = -4.5$, $t_{0.025(2),49} = 2.0$, $p=4.2*10^{-5}$), with winter ambient PM_{10} concentrations being higher than fall PM_{10} concentrations. This is contrary to findings of Cheng *et al.* (2000), who reported that PM_{10} levels were lower during the wintertime than during the summer at the Royal Park sampling site (near Vegreville, Alberta). The presence of snow cover during the winter sampling period should have reduced the resuspension of coarse particles, which are predominant in soil dusts.

In order to determine if the increase in wintertime PM_{10} concentrations coincided with higher $PM_{2.5}$ levels, Pearson correlation coefficients as well as a two-sample t-test to compare fall and winter $PM_{2.5}$ mean concentrations were calculated using Microsoft Excel. Mean fall $PM_{2.5}$ concentrations was 4.4 $\mu g/m^3$, mean winter $PM_{2.5}$ concentration was 8 $\mu g/m^3$. $PM_{2.5}$ data were obtained from the WBEA Ft. McKay monitoring station. Pearson correlation coefficients showed that $PM_{2.5}$ levels were highly correlated with PM_{10} levels both during the fall and winter sampling period. The Pearson correlation coefficients are listed in Table 4-13.

Table 4-13 Correlations of $PM_{2.5}$ with PM_{10} data, and mean $PM_{2.5}$ concentrations for the fall and winter sampling period at Ft. McKay, Alberta.

FALL 1999	$PM_{2.5}$
PM_{10}	0.8
Winter 2000	
PM_{10}	0.9

A two-sample t-test for means was used to determine if there was a statistically significant difference between wintertime and fall $PM_{2.5}$ concentrations, with winter levels being significantly higher (t_{stat}=-5.57, $t_{(0.025(2)44)}$=2.02, p=1.5*10^{-6}) than fall $PM_{2.5}$ levels. Thus, it can be concluded that the higher levels of fine particles, which are generally a product of anthropogenic activity, experienced during the winter sampling period contributed to the elevation of wintertime PM_{10} levels.

To determine whether elevated winter PM_{10} levels were entirely due to an increase in $PM_{2.5}$ levels, Pearson correlation coefficients were generated for PM_{10} outdoor, PM_{10} ambient, $PM_{2.5}$ and the ambient coarse fraction ($PM_{2.5-10}$). The ambient coarse fraction was obtained by subtracting the 24-h $PM_{2.5}$ concentration from the 24-h ambient PM_{10} concentration. Pearson correlation coefficient for outdoor PM_{10} and ambient PM_{10} was 0.92, for outdoor PM_{10} and $PM_{2.5}$ Pearson correlation coefficient was 0.94, and for the outdoor PM_{10} and coarse fraction the Pearson correlation coefficient was 0.89. Thus in all three cases correlation to outdoor PM_{10} was high. Therefore it cannot be concluded that elevated winter PM_{10} levels were exclusively due to and increase in $PM_{2.5}$.

Predominant wind direction from the south support that increased PM_{10} levels during the winter could have originated from industrial activities, however, near field factors (wood burning emissions, idling vehicles, increased emissions due to heating of homes) need to be taken into account prior to drawing conclusions regarding the importance of oil sands emissions.

A paired two-sample t-test was used to determine if there was a statistically significant difference between the fall and winter indoor PM_{10} concentrations. The analysis revealed that indoor concentrations were significantly higher during the fall sampling period than during the winter sampling period ($t_{stat} = 3.2$, $t_{0.025(2)27} = 2.1$, $p=3.4*10^{-3}$). Abt *et al.* (2000) reported higher indoor $PM_{2.5-10}$ concentrations during summer compared to winter, corresponding outdoor concentrations were higher during the summertime. It was concluded that higher summer indoor concentrations were a result of higher outdoor concentrations (Abt *et al.*, 2000). It is not clear what caused higher indoor levels during the fall compared to the winter sampling period in Ft. McKay, since fall outdoor concentrations were lower than winter concentrations. These results could potentially be explained by varying activities indoors during the two sampling periods. However, study participants did not complete time-activity sheets in great detail so conclusions as to what caused the higher fall PM_{10} indoor levels could not be drawn.

5 Summary

The primary objective of this study was to obtain baseline PM_{10} data for the community of Ft. McKay. An additional objective was to identify whether humans are exposed to higher PM_{10} levels indoors or outdoors. Thus, indoor and ambient PM_{10} concentrations were measured to obtain a better estimate of exposure to PM_{10} for the residents of Ft. McKay. The study was conducted during September and October 1999, and January and February 2000, to estimate seasonal variation of PM_{10} levels.

Overall precision of sampling and analysis was good, the quality assurance objective (QAO) for precision of 10% mean relative standard deviation was met.

Results of this study indicate that current ambient PM_{10} levels are well below existing and proposed international PM_{10} air quality standards designed for the protection of human health (U.S. NAAQS, California AQS, EU AQS). Ambient fall PM_{10} concentrations ranged from 1.5 to 20.5 $\mu g/m^3$, the mean ambient PM_{10} concentration was 6.2 $\mu g/m^3$. Ambient winter PM_{10} concentrations ranged from 4.1 to 29.1 $\mu g/m^3$, the mean ambient PM_{10} concentration was 16 $\mu g/m^3$. Outdoor winter PM_{10} concentrations ranged from 5.7 to 27.5 $\mu g/m^3$, the mean outdoor concentration was 17.4 $\mu g/m^3$. Thus ambient/outdoor levels of particulate matter (PM_{10}) were low in comparison to other Alberta, national, or international locations. During the fall sampling period the mean PM_{10} concentrations in Ft. McKay were lower than the mean PM_{10} concentration reported for Alberta rural remote sites. Wintertime mean PM_{10} concentrations in Ft. McKay are comparable to the reported rural influenced site levels, but well below reported rural industrial and urban sites in Alberta. The current oil sands operations are predominantly located south, southeast, and southwest of Ft. McKay, and prevailing winds were from southerly directions during both sampling periods, thus Ft. McKay should have experienced impacts from these industries during the sampling period. Hence, it can be concluded that industrial activities during the sampling period did not elevate ambient PM_{10} levels to levels that exceed current or proposed ambient air quality standards.

Fall indoor PM_{10} concentrations ranged from 6.2 to 212 $\mu g/m^3$, with a mean indoor PM_{10} concentration of 83.4 $\mu g/m^3$. Indoor winter PM_{10} concentrations ranged from 3.4 to 142 $\mu g/m^3$, with a mean indoor PM_{10} concentration of 48.4 $\mu g/m^3$. From the standard deviation it could be seen that indoor concentrations are highly variable compared to ambient PM_{10} concentrations, thus indicating that indoor sources rather than ambient sources have a significant influence on indoor concentrations. Indoor PM_{10} concentrations less than 20 $\mu g/m^3$ for individual homes coincided generally with an absence of smoking in the household and/or the absence of the occupant(s) during the 24-h sampling period. These findings are in line with other studies undertaken in the United States that determined that smoking activity was the predominant activity associated with elevated indoor PM levels (Wallace, 1996).

Indoor mean concentrations of PM_{10} were high, outdoor mean concentrations were low compared to most other studies reviewed. The paired mean indoor/outdoor ratio for the fall sampling period was 19.5, range 1.9 to 76.9 (N=29). The paired mean I/O ratio for the winter sampling period was 5.5, range 0.4 to 27.0 (N=22) for the ambient-indoor locations, and 3.3, range 0.3 to 9.0 (N= 26) for the outdoor-indoor locations.

The I/O ratio obtained for the fall sampling period suggests that significant indoor sources for PM_{10} were present. I/O ratios for the winter sampling period were closer to one than during the fall, however, they are still indicative of strong indoor particle sources. Therefore, it can be concluded that activities within the homes have a greater impact on indoor PM_{10} concentrations than ambient sources. The fact that humans spend the majority of their time indoors, in conjunction with high indoor PM_{10} concentrations, leads to the conclusion that the greatest potential for exposure to PM_{10} and its associated health risks exists in the indoor environment.

Low correlations (0.39) were observed for the outdoor and indoor PM_{10} concentrations. This suggests that indoor PM_{10} levels were not well predicted by outdoor and ambient PM_{10} levels

Air exchange measurements obtained ranged from 0.15 to 0.73 ACH. These rates are typical for houses constructed in the past 20 years. From the low air exchanges observed it can be concluded that particles generated indoors had long air residence times thus allowing for accumulation of particles indoors.

The study determined that PM_{10} concentrations exhibited seasonal variation. Mean winter ambient PM_{10} levels were higher (16 $\mu g/m^3$) than fall ambient PM_{10} levels (6.2 $\mu g/m^3$). These findings are not consistent with findings of other studies undertaken in Alberta (Cheng, 2000). It was expected that winter ambient PM_{10} concentrations would be lower than fall ambient PM_{10} concentrations due to the presence of snow cover and thus reduction of coarse particles from fugitive sources. In order to determine if the increase in wintertime PM_{10} concentrations coincided with higher $PM_{2.5}$ levels, $PM_{2.5}$ data were obtained from the WBEA Ft. McKay monitoring station. Mean fall $PM_{2.5}$ concentrations were significantly lower (4.4 $\mu g/m^3$) than mean winter $PM_{2.5}$ concentrations (8 $\mu g/m^3$). Pearson correlation coefficients (P) showed that $PM_{2.5}$ levels were highly correlated with PM_{10} levels both during the fall ($P = 0.8$) and winter ($P = 0.9$) sampling period. Thus, it can be concluded that the higher levels of fine particles experienced during the winter sampling period, which are generally a product of anthropogenic activity, contributed to the elevation of ambient wintertime PM_{10} levels. However, it can not be concluded, that elevated winter time PM_{10} levels are entirely due to elevated $PM_{2.5}$ levels.

A statistically significant difference was found between the fall and winter indoor PM_{10} concentrations. Indoor concentrations were significantly higher during the fall sampling period (83.4 $\mu g/m^3$) than during the winter sampling period (48.4 $\mu g/m^3$). It is not clear what caused higher indoor levels during the fall compared to the winter sampling period in Ft. McKay, since fall ambient concentrations were lower than winter concentrations. These results could potentially be explained by varying activities indoors during the two sampling periods. However, study participants did not complete time-activity sheets in great detail so conclusions as to what caused the higher fall PM_{10} indoor levels could not be drawn

PM_{10} samples were obtained at five outdoor locations in town and at the WBEA Ft. McKay monitoring station in response to concerns of the residents of Ft. McKay regarding the representativeness of the data collected at the WBEA Ft. McKay monitoring station. High correlations (0.93) were observed between ambient and outdoor concentrations, indicating that PM_{10} measurements obtained at the Ft. McKay WBEA meteorological station were a good representation of the outdoor levels across the community of Ft. McKay during the monitoring period.

6 Conclusion and Recommendations

The results of this study demonstrated that

- Ambient and outdoor PM_{10} levels at current production levels of the oil sands industry in the community of Ft.McKay were well below existing and proposed international PM_{10} standards designed for the protection of public health,
- Indoor mean concentrations of PM_{10} were high. A portion of the study population was exposed to particle levels in the indoor environment that exceed current and proposed international PM_{10} ambient air quality standards designed for the protection of public health. The I/O ratios obtained for the fall and winter sampling periods suggest that significant indoor sources for PM_{10} were present.
- Ambient and outdoor PM_{10} levels were not a good predictor of indoor PM_{10} levels.
- PM_{10} concentrations exhibited seasonal variation, with winter ambient levels being higher than fall ambient levels. Indoor PM_{10} concentrations were significantly higher during the fall sampling period than during the winter sampling period. It is not clear what caused higher indoor levels during the fall compared to the winter sampling period in Ft. McKay.
- PM_{10} measurements obtained at the Ft. McKay WBEA meteorological station were a good representation of the outdoor levels across the community of Ft. McKay during the monitoring period.

From this study the following recommendations for further studies can be made:

- To better estimate the influence of outdoor concentrations on indoor concentrations data should be collected in a manner that permits for longitudinal rather than cross-sectional data analysis. Since inter-home variability can mask intra-home correlation.
- To better assess the impact of elevated PM levels on human health, size-selective sampling (i.e. PM_{10}, $PM_{2.5}$, and $PM_{1.0}$) and enhanced chemical characterization should be performed in conjunction with analysis of detailed time activity data.
- Use of the MiniVol sampler should be limited to environments with temperatures above 0°C or a heater for the MiniVol should be used to avoid failure of the sampler. The MiniVol was designed for operation in above 0°C temperatures (Seese, 2000), thus it is unknown at this point if extremely cold temperatures affect the performance characteristics of the sampler and its inlet.

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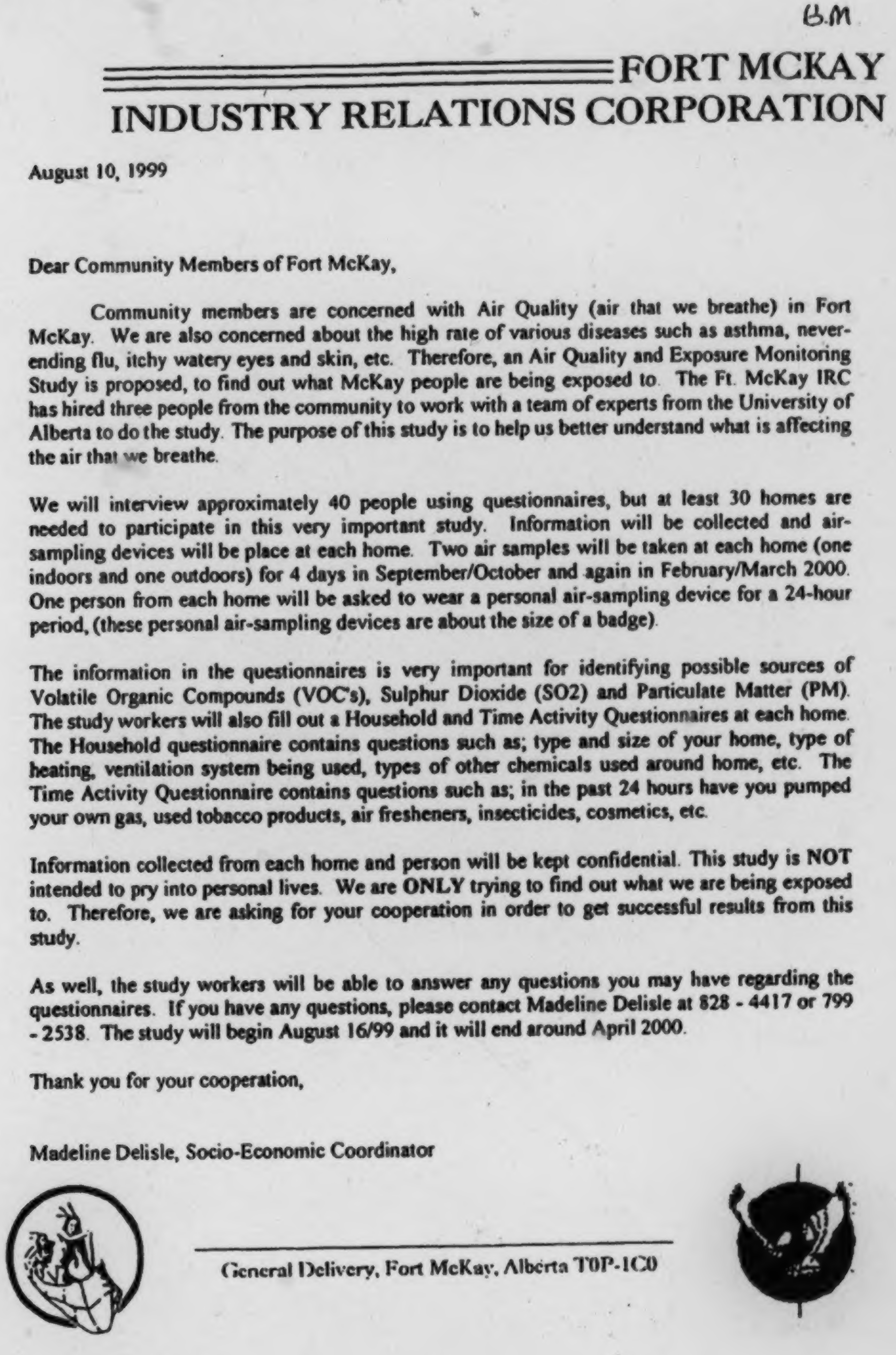
8 Appendices

8.1 Appendix A

Recruitment Package

8.1.1 Community Information Letter



B.M

FORT MCKAY
INDUSTRY RELATIONS CORPORATION

August 10, 1999

Dear Community Members of Fort McKay,

Community members are concerned with Air Quality (air that we breathe) in Fort McKay. We are also concerned about the high rate of various diseases such as asthma, never-ending flu, itchy watery eyes and skin, etc. Therefore, an Air Quality and Exposure Monitoring Study is proposed, to find out what McKay people are being exposed to. The Ft. McKay IRC has hired three people from the community to work with a team of experts from the University of Alberta to do the study. The purpose of this study is to help us better understand what is affecting the air that we breathe.

We will interview approximately 40 people using questionnaires, but at least 30 homes are needed to participate in this very important study. Information will be collected and air-sampling devices will be place at each home. Two air samples will be taken at each home (one indoors and one outdoors) for 4 days in September/October and again in February/March 2000. One person from each home will be asked to wear a personal air-sampling device for a 24-hour period, (these personal air-sampling devices are about the size of a badge).

The information in the questionnaires is very important for identifying possible sources of Volatile Organic Compounds (VOC's), Sulphur Dioxide (SO2) and Particulate Matter (PM). The study workers will also fill out a Household and Time Activity Questionnaires at each home. The Household questionnaire contains questions such as; type and size of your home, type of heating, ventilation system being used, types of other chemicals used around home, etc. The Time Activity Questionnaire contains questions such as; in the past 24 hours have you pumped your own gas, used tobacco products, air fresheners, insecticides, cosmetics, etc.

Information collected from each home and person will be kept confidential. This study is NOT intended to pry into personal lives. We are ONLY trying to find out what we are being exposed to. Therefore, we are asking for your cooperation in order to get successful results from this study.

As well, the study workers will be able to answer any questions you may have regarding the questionnaires. If you have any questions, please contact Madeline Delisle at 828 - 4417 or 799 - 2538. The study will begin August 16/99 and it will end around April 2000.

Thank you for your cooperation,

Madeline Delisle, Socio-Economic Coordinator

General Delivery, Fort McKay, Alberta T0P-1C0

8.1.2 Instructions for Fieldstaff

Fort McKay Air Quality and Exposure Study
Instructions for Field Staff

Pre-visit

distribute informational letter to all households in Fort McKay

Recruitment Visit

Step 1:

Before you knock on the door of the household, fill in section A and B of **Recruit Status Form**

Step 2:

identify yourself and ask to speak to the owner or head of the household

briefly explain the purpose of the visit. e.g. "My name is ____________, and I am working for the Fort McKay Industrial Relations Corporation on an air quality and exposure study here in Fort McKay. I am here to ask you whether you would be interested in participating in the study."

If the people do not know what you are talking about, ask if they received and read the information letter:

if no, give them a copy of the letter, and give them a chance to read it. Then ask them if they are interested in participating

if yes, continue

Step 3:

give them a copy of the **Participant Information Sheet**

briefly explain the study, for example what we are doing, where we are putting the samplers, how long are the samplers going to be there, by referring to the letter and information sheet. Also, show them the pictures of the samplers for VOC, SO_2 and PM_{10}

make sure that you indicate the following:

the commitment required by the participant, for example they have to be available when we are there to drop off and pick up the samplers and one person from the household has to be willing to participate in the personal monitoring study (refer to participant information sheet and explain each step in the study).

advise that they are not obligated to participate and may withdraw at any time

advise participant that these data will be stored in a secure location by the University of Alberta for 7 years

advise participant that results from the study can be provided to them when available

Step 4:

ask if they have any questions or concerns. If you cannot answer a question, refer them to Madeline.

ask if they would like to participate in the study
if no, write down the reason in section B of the **Recruit Status Form.** Thank them for their time and proceed to the next home
if yes, using the **Sampling Schedule,** fill in the name and appointment date that they will be available.

Step 5:
Fill out section C of the **Recruitment Status Form**. Following the instructions laid out in **Recruitment Status Form**, section C, choose the individual that will be wearing the personal sampler
Fill out the **Participant Consent Form** and have the individual that has agreed to wear the personal sampler sign the form.

Reminder Visit
one week before the scheduled sampling time, contact the participants again to confirm that the appointment is still okay. If not, reschedule the appointment

8.1.3 Participant Information

UNIVERSITY OF ALBERTA
Civil and Environmental Engineering

Title of the Project: ***Air Quality & Exposure Monitoring in the Community of Fort Mackay: A Baseline Assessment***

Co-investigators: M. Delisle, IRC

Field Investigators: B. Mueller, R. Miyagawa, S. Ranganathan

Purpose of Research:

Public concern exists about the impact of local oil sands industries in the community of Fort MacKay.

Background Information:

The environment in which we live is important to our health. We are exposed to pollution in our air, food, water, and soil. This study focuses on industrial pollution and its effect on local air quality.

The air pollutants being investigated are particulate matter (PM), sulfur dioxide (SO_2) and volatile organic compounds (VOC). Common sources of PM include cars, industries, road dust, tobacco smoke and wind erosion. Common sources of SO_2 include the burning of fossil fuels (car, industry, etc), residential fuel consumption and tobacco smoke. Common sources of VOC include cars, industries, forest fires, tobacco smoke, building materials and cleaning products.

Why did you approach me to participate?

Study participants were chosen by a random selection of homes in the community.

What if I do not want to participate?

Your participation in the study is strictly voluntary.

What is my role as a participant?

If you choose to participate, the study team will visit you several times in the fall and again in the winter. During the first visit, the researchers will explain the study and answer any questions you may have. They will also schedule a date and time for a visit by the sampling team.

On the chosen day, the sampling team will visit and place air sampling devices both inside and outside of your home. If you are participating in the personal monitoring study, you will be asked to wear a sampling badge for approximately 24-hour period. The sampler is small and silent and clips to the collar of your shirt or coat. You will be asked to complete a questionnaire on the characteristics of your household.

At the end of the sampling period, the investigators will return to collect the samplers. At this time, you will be interviewed briefly (approx. 30 min) about household activities during the sampling period. If you wore a personal monitor, you will also be asked to complete a 24-hour diary of your activities during the sampling periods.

This process will be repeated during the winter sampling season.

Are there any risks or benefits?

There are no health and safety risks associated with this study. The direct benefits include the results of your home's air quality. This information will be available upon request in August 2000.

How will the information collected be kept confidential?

The records relating to this study are confidential. The investigators will have access to these reports to develop research reports. Any report published as a result of this study will not identify you by name.

Whom can I call with questions?

If you have questions about this study, you may contact

Principal Investigator:

Dr. Warren Kindzierski
University of Alberta
492-0247

8.1.4 Recruit Consent Form

Sampling Unit #: ___________

Title of Project: COMMUNITY AIR QUALITY AND EXPOSURE ASSESSMENT IN FORT MCKAY, ALBERTA

Please answer these questions by circling "YES" or "NO":

Do you understand that you have been asked to be in a research study?	YES	NO
Have you received and read a copy of the Information Letter?	YES	NO
Have you received and read a copy of the Information Sheet?	YES	NO
Have you had a chance to ask questions and talk about the study?	YES	NO
Do you understand that you are free to refuse to take part or withdraw from the study at any time? You do not have to give a reason.	YES	NO
Do you understand that all information collected for this study is private and that your name will not be used in any reports on this study?	YES	NO

This study was explained to me by: ______________________________

Name of field worker

I agree to take part in this study:

______________________________ ______________________

Signature of participant Date

______________________________ ______________________

Name of participant (please print) Phone No. (optional)

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate:

______________________________ ______________________

Signature of field worker Date

8.1.5 Participant Information Sheet

Fort McKay Air Quality and Exposure Study

Participant Information Sheet

The study team will be taking samples of the air inside and outside of homes in Fort McKay. These samples will be used to measure the level of pollutants in the air inside your home, outside your home, and in the air being breathed by one member of the household.

If you agree to participate, you will be visited by the study team three times in the fall (September/October), and three times in the winter (February/March). The purpose of each visit is given below.

Visit 1 – Sampler Drop-off

the study team will arrive at the scheduled time
air samplers will be set up inside and outside the house
indoor samplers will be placed in the main living area of the home
three types of samplers will be used:
two of the samplers are small (5-10 cm across) and silent badges. These samplers will be left in place for 4 days.
the third sampler is approximately 7" in diameter and 20" high. It will be left in place for only 1 day.
one adult from the household will be selected to wear a personal sampler for a 24-hour period
the sampler is a small badge that clips onto the collar of a shirt or coat
it should be worn at all times during the sampling period, but can be removed and placed nearby when sleeping or bathing.
you will be interviewed to complete a Household Characteristics Questionnaire. This questionnaire includes general information about your home which may affect levels of air pollutants. We only need information to explain the air sample results. We do not intend to pry into your personal lives.

Visit 2 (24 hours later) – Sampler Pickup #1

the study team will return to the home the next day at the same time of day as Visit 1

the large indoor and outdoor samplers will be collected

the personal sampler will be collected

the individual who wore the sampler will be asked to complete a 24-hour activity survey, this will help identfy activities which may have affected their exposure to pollutants

the 24-Hour Household Activities Questionnaire will be completed by interview. This questionnaire identifies activities which took place inside the home which may have affected levels of air pollutants.

Visit 3 (4 days later) – Sampler Pickup #2

the sampling team will return to the home 4 days after the first visit at the same time of day

the remaining indoor and outdoor samplers will be collected

the 4-day Household Activities Questionnaire will be completed by interview. This questionnaire identifies activities, which took place inside the home which may have affected levels of air pollutants.

8.1.6 Recruitment Status Form

Fort McKay Air Quality and Exposure Study

Recruitment Status Form

Section A. Household Identification

List No. :__________ (refer to **Recruitment List**)
Household Unit No.:
Housing Type:__________ (House or Trailer)

Section B. Record of Recruitment Visits

Day of Week	Date	Time	Result (refer to list possible results below)

Possible Results

VACANT
NO ONE HOME (followup visit required)
NEEDS MORE INFO (followup visit required)
AGREED TO TAKE PART (complete Section C)
REFUSED TO TAKE PART (give reason if possible)

Section C. Participant Information

Sample No.: (refer to **Sampling Schedule**)
Phone No.: (please indicate if there is no phone in the home)

One adult (18 and older) from the home must be selected to wear a sampling badge for 24 hours. This person must be available to the sampling team at the time of Visits 1 and 2.

1. How many adults in the home are willing and able to take part in the personal sampling study?

____

2. Which of these adults has the next upcoming birthday? Write their name in the space provided below.

Name: ____

3. Have the person named above complete the **Participant Consent Form.**

Sampling Reminder

Visit 1 ______________________________

Visit 2 ______________________________

Visit 3 ______________________________

If you have any questions, or need to change the appointment, call Madeline at 799-2538 or 828-4417.

8.1.8 Sampling Schedule Form

Please assign Sample 1 - 30 first.							
Use Sample 30 - 40 only if no Sample 1- 30 appointment is possible							
Sample 1				**Sample 2**			
List #:				**List #:**			
Name:				**Name:**			
Visit #	**Date**	**Time**	**Activity**	**Visit #**	**Date**	**Time**	**Activity**
1	09/23/99	4:00 PM	DO, Q1	1	09/23/99	7:30 PM	DO, Q1
2	09/24/99	4:30 PM	PU PM,PVOC, Q2	2	09/24/99	8:00 PM	PU PM,PVOC, Q2
3	09/26/99	4:30 PM	PU SO2,VOC, Q3	3	09/26/99	8:00 PM	PU SO2,VOC, Q3
Sample 3				**Sample 4**			
List #:				**List #:**			
Name:				**Name:**			
Visit #	**Date**	**Time**	**Activity**	**Visit #**	**Date**	**Time**	**Activity**
1	09/24/99	6:30 PM	DO, Q1	1	09/25/99	4:00 PM	DO, Q1
2	09/25/99	7:00 PM	PU PM,PVOC, Q2	2	09/26/99	4:30 PM	PU PM,PVOC, Q2
3	09/27/99	7:00 PM	PU SO2,VOC, Q3	3	09/28/99	4:30 PM	PU SO2,VOC, Q3
Sample 5				**Sample 6**			
List #:				**List #:**			
Name:				**Name:**			
Visit #	**Date**	**Time**	**Activity**	**Visit #**	**Date**	**Time**	**Activity**
1	09/25/99	7:30 PM	DO, Q1	1	09/26/99	6:30 PM	DO, Q1
2	09/26/99	8:00 PM	PU PM,PVOC, Q2	2	09/27/99	7:00 PM	PU PM,PVOC, Q2
3	09/28/99	8:00 PM	PU SO2,VOC, Q3	3	09/29/99	7:00 PM	PU SO2,VOC, Q3
Sample 7				**Sample 8**			
List #:				**List #:**			
Name:				**Name:**			
Visit #	**Date**	**Time**	**Activity**	**Visit #**	**Date**	**Time**	**Activity**
1	09/27/99	4:00 PM	DO, Q1	1	09/27/99	7:30 PM	DO, Q1
2	09/28/99	4:30 PM	PU PM,PVOC, Q2	2	09/28/99	8:00 PM	PU PM,PVOC, Q2
3	09/30/99	4:30 PM	PU SO2,VOC, Q3	3	09/30/99	8:00 PM	PU SO2,VOC, Q3
Sample 9				**Sample 10**			
List #:				**List #:**			
Name:				**Name:**			
Visit #	**Date**	**Time**	**Activity**	**Visit #**	**Date**	**Time**	**Activity**
1	09/28/99	6:30 PM	DO, Q1	1	09/29/99	4:00 PM	DO, Q1
2	09/29/99	7:00 PM	PU PM,PVOC, Q2	2	09/30/99	4:30 PM	PU PM,PVOC, Q2
3	10/01/99	7:00 PM	PU SO2,VOC, Q3	3	10/02/99	4:30 PM	PU SO2,VOC, Q3

DO Drop off	PM Particulate Matter	SO2 Sulfur Dioxide
PU Pick up	PVOC Personal VOC Sampler	Q Questionnaire

8.2 Appendix B

Questionnaires and Field Forms

8.2.1 Household Questionnaire (Q1)

FT. MCKAY AIR QUALITY STUDY

QUESTIONNAIRE: HOUSEHOLD CHARACTERISTICS (Q1)

Sample No: ____________________ Interviewer: ____________________

Date: ____________________

Title of Project: ***COMMUNITY SAMPLING OFPARTICULATE MATTER, SULPHUR DIOXIDE AND VOLATILE ORGANIC COMPOUNDS IN FORT McKAY***

Principal Investigator: Warren Kindzierski
University of Alberta

Co-Investigators: Fort McKay Industrial Relations Corporation

Field Investigators: Russ Miyagawa, Bettina Mueller, Sunita Ranganathan
University of Alberta
Phone: 492-8548

Instructions:

The information obtained by this questionnaire will be held in strict confidence and will be used for research purposes only. All results will be summarized for groups of people; no information regarding individual persons will be released without the consent of the individual.

Your answers help to determine things about your home that may affect indoor air quality. Before you answer a question as "unknown", please refer to the glossary of terms for unfamiliar words or ask your interviewer for help.

Thank you for your co-operation.

A. Household and Participant Identification:

1. Participant Name: ______________________

2. Participant Phone No.: ______________________

3. Street Address, P.O. Box ______________________

4. City/Hamlet: ______________________

B. Household Habitants:

5. Who lives in the house?

Person #	**Name (optional)**	**Age Category ***	**Smoker (y/n)**	**Occupation**
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Age Categories: **1** = 0-12 years; **2** = 12-17 years; **3** = 18 years and over

Are there any pets in your household?

☐ yes ☐ no

If yes, what kind of pets do you have?

☐ dog ☐ cat ☐ other ______________________

C. Type of House

6. Which best describes your home?

☐ a mobile home or trailer

☐ a one-family house detached from any other house

How big is the house, without the basement?
_______ square feet, or _______square metres ☐ check box if estimated

8. Do you have a finished basement?
☐ yes ☐ no ☐ unknown

9. How big is the basement?
______ square feet, or ______square metres
☐ check box if estimated

In what year was the house originally built?__________________

Is there an unpaved driveway on your property?
☐ yes ☐ no

Is there a garden on your property
☐ yes ☐ no

13. Do you have an outdoor barbecue, firepit or burnbarrel?
☐ yes ☐ no

14. Do you have a smokehouse?
☐ yes ☐ no

15. While you are awake, in which area of your home do you spend MOST of your time?
☐ bedroom ☐ kitchen
☐ spare room ☐ living room
☐ dining room ☐ rec room
☐ other______________________

D. Heating, Ventilation, and Air Conditioning Systems:

16. Does the house have an air conditioner?
☐ yes ☐ no ☐ unknown
If yes, what type? ☐ central ☐ room
If it is a room air conditioner, what room is it in?________________

17. Does the house have any fans for extra ventilation?
☐ yes ☐ no ☐ unknown
If yes, what type(s)?
☐ portable fan ☐ ceiling fan ☐ bathroom fan
Location(s)?_______________________________________

18. Does the house have an air purification system installed?
☐ yes ☐ no ☐ unknown
If yes, what type?________________________________

19. Does the house have any range hoods, fume hoods?
☐ yes ☐ no ☐ unknown
If yes, where is it? ________________________________
Where does it vent to?
☐ outside ☐ inside ☐ unknown

20. Have you had your gas pipes/gas appliances checked for leaks?
☐ yes ☐ no ☐ unknown
If so, when? ____

21. How do you heat your home? Where are the heaters located?

Type of System	Main	Second	Third	Location
forced air furnace	☐	☐	☐	________
gravity furnace	☐	☐	☐	________
radiant heat – wall	☐	☐	☐	________
radiant heat – floor	☐	☐	☐	________
fireplace	☐	☐	☐	________
stove	☐	☐	☐	________
room heater	☐	☐	☐	________
portable heater	☐	☐	☐	________
other ____________	☐	☐	☐	

____

22. What type of fuel do you use?

Type of fuel	Main	Second	Third
natural gas	☐	☐	☐
fuel oil	☐	☐	☐
electricity	☐	☐	☐
kerosene	☐	☐	☐
wood	☐	☐	☐
other ____________	☐	☐	☐

23. Do you keep the house at the same temperature all the time?

☐ yes ☐ no ☐ unknown

24. Does the heating system have a combustion air supply?

☐ yes ☐ no ☐ unknown

25. Does the heating system have a fresh air return?

☐ yes ☐ no ☐ unknown

26. Do you use a humidifier

☐ room humidifier ☐ attached to furnace ☐ no

☐ unknown

Do you have a sump pump?

☐ yes ☐ no ☐ unknown

E. Attached Structures:

28. Does the house have any attached structures?

☐ yes ☐ no ☐ unknown

If yes, what type(s)?

☐ garage ☐ shed/shop ☐ porch

☐ greenhouse ☐ other ____________________

If no then go to Question 33.

Do you start your vehicle in the garage

☐ yes ☐ no ☐ unknown

30. Does the attached structure(s) have a door that opens into the house?

☐ yes ☐ no ☐ unknown

If yes, is this door(s) usually left open or closed?

☐ yes ☐ no ☐ unknown

31. Does the attached structure have a heating system?

☐ yes ☐ no ☐ unknown

If yes, what type? ______________________________

Please use the categories listed in question (21,22).

32. Does the attached structure have any ventilation or exhaust system(s)?

☐ yes ☐ no ☐ unknown

If yes, what type?

☐ window/overhead door ☐ exhaust system ☐ fan

If exhaust, where does it vent to? ☐ outside ☐ inside

F. Household Sources of VOCs, PM, SO_2:

33. Are all of your household appliances (cooking stove, hot water heater, clothes dryer, etc.) electric? If no, please complete the below table.

☐ yes ☐ no ☐ unknown

	Type of Fuel (✔)		
Type of Appliance	natural gas	other (specify)	location
cooking stove			
hot water heater			
clothes dryer			
other ________			

34. Do you ever use the cooking stove for heating your home?

☐ yes ☐ no ☐ unknown

35. Is the clothes dryer vented to the outside?

☐ yes ☐ no ☐ unknown

36. Do you have carpet in your home?

☐ yes ☐ no ☐ unknown

37. How much carpet would you guess your home has?

☐ <25% ☐ 25 to 50% ☐ 50 to 75% ☐ >75%

38. Has any part of the house had carpet installed within the past year?

☐ yes ☐ no ☐ unknown

If yes, than within past: ☐ 3 months ☐ 6 months

Where was it installed? ______________________________

39. Do people smoke inside the house or any of the attached structures?

☐ yes ☐ no ☐ unknown

Comments:

____

____

____

______________________________**End of Questionnaire**

GLOSSARY OF TERMS:

If the term you are looking for is not here or you still do not understand the question then please contact one of the investigators.

attached structure	a building which is physically connected to your home. This may include a garage, shed, shop, greenhouse, etc.
combustion air supply	an (insulated) air duct which supplies fresh air from outside to the furnace room for combustion. It is not directly attached to the furnace and it usually ends just above the floor with a perforated cap.
duct	a pipe or conduit which moves air.
exhaust system	an electric fan which draws air out of an area and blows it outside (vents outside), or an electric fan which circulates the air through a filter and blows it back inside (vents inside).
fireplace/stove	a wood, gas, or coal fueled fire burning unit.
forced air furnace	this is a furnace where the warm air is pushed through the furnace ducts by the furnace's electric fan.
fresh air return	an (insulated) air duct which supplies fresh air from outside to the furnace as a fresh air supply for the house. It is directly attached to the furnace's air intake duct.
gravity furnace	an older style furnace where the warm air rises naturally through the furnace ducts without the aid of a fan.
mechanical	a motorized system requiring power to run.
portable heater	a portable heater which is usually fueled by propane, kerosene, or electricity.

radiant heat	a heating system which circulates hot water from a boiler throughout the house. The heat from the hot water is given off of pipes that run along the base of a wall, or run underneath the floor.
room heater	fixed heater located in a specific room, usually intended to supplement the main heating system.
single family house	a house which was originally designed to accommodate a single family. This does not include a duplex, a fourplex, an apartment building or any other multifamily housing.
vent	process of blowing air or fumes usually out the end of a pipe. If the air is blown to the outside than this is venting outside, if the air is blown back inside of the house than this is venting inside.
ventilation	the movement of air in a space. It can be either mechanical ventilation through the use of an electric fan, or it can be natural ventilation achieved by opening windows or doors.

8.2.2 Personal Exposure and Activity Questionnaire (Q2)

FORT MCKAY AIR QUALITY STUDY

Personal Exposure and Activity Questionnaire (Q2)

Sample #.: ____________________ **Interviewer:** ____________________

Date: _____/_____/_____

Did you have your drapes, carpet, or furniture professionally-cleaned during the past 24 hours?

☐ Yes ☐ No

Did you vacuum your home during the past 24 hours?

☐ Yes ☐ No

Were any windows left open in your home during the past 24 hours?

☐ Yes ☐ No

Have you used tobacco, in any form, during the past 24 hours?

☐ Yes (GO TO QUESTION 3a) ☐ No (GO TO QUESTION 4)

Which of the following tobacco products have you used in the past 24 hours?

☐ Cigarettes ☐ Cigars ☐ Pipe ☐ Snuff ☐ Chewing tobacco

Approximately how many cigarettes did you smoke during the past 24 hours?

____

Were you exposed to second-hand tobacco smoke during the past 24 hours (in enclosed area with active smokers for more than 15 minutes)?

☐ Yes ☐ No

For how long were you exposed to second-hand smoke during the past 24 hours?

____|______

Were you exposed to any other smoke (forest or camp fires, smoke houses, etc.) during the past 24 hours? If yes, please specify the source(s) of the smoke.

☐ Yes (specify below) ☐ No

Specify:____

Have you used or worked with insecticides, pesticides, or herbicides in the past 24 hours?

☐ Yes ☐ No

Have you operated any gas-powered appliances or tools in the past 24 hours? If specify the appliance or tool and type of fuel.

☐ Yes (specify below) ☐ No

	Appliance/Tool	Fuel
1.	____________	____________
2.	____________	____________
3.	____________	____________

Have you travelled by car, truck or other gas-powered vehicle in the past 24 hours? Have you walked or bicycled near a major roadway in the past 24 hours?

☐ Yes (GO TO QUESTION 7a.) ☐ No (GO TO QUESTION 8)

Please provide details of any trips you have made:

Trip	Type of Vehicle/Duration	Windows	Heavy Traffic?
1.	____________ min	open ☐ closed☐	yes☐ no☐
2.	____________ min	open ☐ closed☐	yes☐ no☐
3.	____________ min	open ☐ closed☐	yes☐ no☐
4.	____________ min	open ☐ closed☐	yes☐ no☐
5.	____________ min	open ☐ closed☐	yes☐ no☐
6.	____________ min	open ☐ closed☐	yes☐ no☐

Have you worked at or visited any of the following businesses during the past 24 hours? (Check all that apply)

Worked	Visited	Worked	Visited
☐	☐ Painting	☐	☐ Dry cleaning
☐	☐ Chemical/plastics plant	☐	☐ Petroleum plant (Oil sands)
☐	☐ Service station/garage	☐	☐ Furniture refinishing/repair
☐	☐ Wood processing plant	☐	☐ Printing
☐	☐ Hospital	☐	☐ Renovations/construction

Have you performed any of the following activities during the past 24 hours? (Check all that apply)

☐ Metal work
☐ Plumbing
☐ Automotive or other mechanical repair
☐ Painting
☐ Furniture refinishing/repair
☐ Welding
☐ Plastics work
☐ Auto body repair
☐ Gluing/caulking
☐ Floor waxing/strippping
☐ Other renovations/redecorating – specify: ______________________
☐ Used degreasers
☐ Used air fresheners/deodorizers
☐ Used other cleaning products – specify: ______________________
☐ Scale model building
☐ Other hobbies/craftwork
☐ Other activities which may have led to exposure to chemicals:

Please indicate any other events during this time period which may have led to exposure to chemicals or airbourne pollutants:

END OF QUESTIONNAIRE

8.2.3 Household Activity Questionnaire (Q3)

FORT MCKAY AIR QUALITY STUDY
Household Activity Questionnaire (Q3)

Sample No.: ____________________ **Interviewer:** ____________________

Date: _____/_____/_____

Did you have your drapes, carpet, or furniture professionally-cleaned during the past 4 days?

☐ Yes ☐ No

Did you vacuum your home during the past 4 days?

☐ Yes ☐ No

Were any windows left open in your home during the past 4 days?

☐ Yes ☐ No

Have you or visitors used tobacco inside the home, in any form, during the past 4 days?

☐ Yes (GO TO QUESTION 3a) ☐ No (GO TO QUESTION 4)

Which of the following tobacco products were used in the past 4 days?

☐ Cigarettes ☐ Cigars ☐ Pipe

Approximately how many cigarettes/cigars were smoked during the past 4 days?

____

Did you generate any other smoke (forest or camp fires, smoke houses, etc.) at your residence during the past 4 days? If yes, please specify the source(s) of the smoke.

☐ Yes (specify below) ☐ No

Specify: ____

Have you used insecticides, pesticides, or herbicides in the past 4 days?

☐ Yes ☐ No

2

Have you operated any gas-powered appliances or tools at your residence in the past 4 days? If specify the appliance or tool and type of fuel.

☐ Yes (specify below) ☐ No

	Appliance/Tool	Fuel
1.	____________	____________
2.	____________	____________
3.	____________	____________

Have you performed any of the following activities during the past 4 days at your residence?
(Check all that apply)

☐ Metal work	☐indoor	☐outdoor
☐ Welding	☐indoor	☐outdoor
☐ Plumbing	☐indoor	☐outdoor
☐ Plastics work	☐indoor	☐outdoor
☐ Automotive or other mechanical repair	☐indoor	☐outdoor
☐ Auto body repair	☐indoor	☐outdoor
☐ Painting	☐indoor	☐outdoor
☐ Gluing/caulking	☐indoor	☐outdoor
☐ Furniture refinishing/repair	☐indoor	☐outdoor
☐ Floor waxing/strippping	☐indoor	☐outdoor
☐ Other renovations/redecorating – specify: ____________________	☐indoor	☐outdoor
☐ Used degreasers	☐indoor	☐outdoor
☐ Used air fresheners/deodorizers		
☐ Used other cleaning products – specify: ____________________	☐indoor	☐outdoor
☐ Scale model building	☐indoor	☐outdoor
☐ Other hobbies/craftwork	☐indoor	☐outdoor

☐ Other activities which may have led to exposure to chemicals:

____

____

____

____

____

Do you have any of the following items? Where is it stored?
Did you use it recently, and if so where?
Please complete the below table.

Item	Do you have? (y/n)	Storage location? (specify floor and room)	Recent use? (n/d/wk)	Where was recent use (if different from storage)? (specify floor and room)
Gas, oil				
Propane				
Other fuels				
Vehicles				
Rec. vehicles				
Pesticides/ Fertilizers				
Paint or varnish				
Solvents				
Glues				
Dirty work clothing				
Clean/disinf. Agents				
Air deodorant				
Mothballs				
Cosmetic/hair products				
Aerosol spray				
Office equip.				

Please indicate any other events during this time period which may have led to exposure to chemicals or airbourne pollutants:

____

____

____

____

____

____

END OF QUESTIONNAIRE

8.2.4 *Field Forms*

Chain of Custody Form

Time Activity Log

Air Exchange Data Sheet

Field Data Log

Chain of Custody Form
Ft. McKay AQ Study Winter 2000

Weighing Lab			
Filter ID		Weighing Date	
Analyst Name	**A. Wharmby**	Shipped Via	**Pick up**
Shipment Date			
Filter Expiry			
Field Office			
Date received		Field Scientist	**B. Mueller**
Shipment OK?	Y N		
Post Sampling			
Date		Filter OK?	Y N
Type of Sample	**Indoor**	**Outdoor**	
Associated Samples (enter filter ID)			
Replicate	Outdoor	Indoor	
Field Filter Shipping			
Date shipped			
Shipped via	**Hand delivered**		
Destination	**Vegreville ARC**		
Weighing Laboratory			
Date received		Analyst Name	**A. Wharmby**
Shipment OK?	Y N	Weighing Date	
Shipment Date		Shipped Via	**Pick up**
Elemental Analysis			
Date analysed		Analyst Name	
Type of Analysis	**SEM INAA**		

FORT MCKAY AIR QUALITY STUDY
Time-Activity Log

Sample No.: ______________

Date: ____/____/____

1. Record the approximate starting and ending times for each activity during the sampling period.
2. Place a check mark (✔) in the appropriate location box.
3. Record a general description of the activity and more specific information about the location (e.g. indicate the room in the home in which the activity occurred).

TIME		INDOORS			OUTDOORS		DESCRIPTION OF ACTIVITY/LOCATION
From	To	Home	Work or School	Other	Vehicle or Roadway	Other	

Air Exchange Data Sheet

House #: ____________

		Deployed		Collected		
Source	**ID#**	**Date**	**Time**	**Date**	**Time**	**Location**
1						
2						
3						
4						
5						

		Deployed		Collected		
CAT	**ID #**	**Date**	**Time**	**Date**	**Time**	**Location**
1						
2						
1a						
2a						
blank						

FLOOR PLAN:
Sketch home and indicate location of all sources and CATs.

Particulate Matter (PM 10) Sampling Field Data Log

Ft. McKay AQ Study Winter of 2000

Sampling Date:

Field Scientist:

Page _____of ______

Start:		**End:**	
Atm Press [mmHg]	**Wind**	**Atm Press [mmHg]**	**Wind**
Amb Temp [°C]	**r.H. [%]**	**Amb Temp [°C]**	**r.H. [%]**

Site ID	**Sample Type**	**Sampler ID**	**Battery ID**	**Filter ID**	**Start**			**End**		
					Clock time	Elap time	Roto Flow	Clock time	Elap time	Roto Flow
	Indoor									
	Comment									
	Outdoor									
	Comment									
	Met Station									
	Comment									
	Replicate									
	Comment									
	Comment									

8.3 Appendix C

Determination of Air Exchange Rate

8.3.1 Draft Protocol for the Determination of Air Exchange Rate in a Home

Robert A. Weker, Harvard School of Public Health, Boston, MA.

AIR EXCHANGE MEASUREMENT

1. Scope

This document is intended to provide the necessary details for the determination of indoor/outdoor air exchange rates in relatively small enclosures such as homes, apartments, or small offices. Following the procedure below, air exchange rates can be quantified over the range 0.10 to 2.5 air changes per hour (ACH). The limit of detection is about 3.0 ACH.

2. Introduction

The measurement of air exchange rate (AER) is accomplished using a tracer gas under steady-state conditions, and a passive sampling technique followed by sample analysis with a gas chromatograph and electron capture detector (GC/ECD).

This method is based upon the technique developed by Dietz et al(1). An inert, non-toxic, tracer chemical, perfluorinated methylcyclohexane (PMCH), is allowed to permeate into the enclosure for 24 hours. During this period a steady-state concentration is theoretically established based upon partly the permeation rate of the PMCH source, the volume and temperature of the enclosure and its average air exchange rate. Now, the passive sampling device, a capillary adsorption tube (CAT), is located in the enclosure and allowed to collect PMCH for a fixed period of time ranging from 12 hours to one week. The PMCH permeation source remains in the enclosure for the duration of the sampling period. The passive sampling device is returned to the laboratory for determination of the amount of PMCH collected. Given the above variables, the collection rate of the CAT, and conversion factors, the average air exchange rate can be calculated. The PMCH source is removed one day after CAT sampling is complete, then it is returned to the lab for post-experimental permeation rate verification.

3. PMCH sources

PMCH sources have a nominal permeation rate of 375 ng/min. at 24-25 degrees C. and a useful lifetime of about 4-5 years. The permeation rate is proportional approximately to temperature, 3% per degree C. For a batch of sources prepared with the same materials at the same time the permeation rate has an associated relative standard deviation (RSD) less than 3%.

A. Preparation

Apparatus, Materials, Supplies

22 mm aluminum bullet shells and holder
PMCH (Aldrich Chemical)
50 ml or 100 ml graduated glass beaker
autopipette for transferring 0.4 ml
silicone rubber solid tubing
aluminum plug-cutting tool
silicon high vacuum grease
crimper
7 mm punch
razor blades, single edge
electromechanical vibrating engraver or equivalent
lab tissue paper
disposable rubber gloves
#3 cork borer
polyurethane foam
labels 0.5cmx2.5cm
clear tape 3/4"

Procedure

1. Engrave an ID on each bullet shell. The ID should be HSPH yy-nnn where yy are the last two digits of the year made and nnn is the next sequential number.
2. Using the punch and hammer, carefully expand the open end of each shell only slightly to facilitate later insertion of the silicone plug. Place the engraved shells sequentially in the shell holder.
3. Lay a piece of silicone rubber solid tubing in the aluminum plug jig and carefully cut fixed length plugs with a razor blade. Cut one plug for each source.
4. Using gloves, apply a very thin layer of silicone grease to the circumferential surface of the plugs being careful not to get grease on the flat surfaces.
5. Calculate the total ml of PMCH needed: number of PMCH sources multiplied by 0.4 ml per source.
6. Transfer the calculated amount of PMCH plus a small additional amount to the graduated glass beaker.
7. With the autopipette, transfer 0.4 ml PMCH to 6 shells.
8. Carefully insert/press a rubber plug into each shell until it is just flush with the top edge.
9. Crimp the plugged end of each shell with the special crimper tool.
10. Remove excess grease if any with a piece of tissue and replace the shell in the holder.
11. With a hack saw cut the polyurethane foam into blocks of 2cm(L) x 3cm(W) x 5cm(H).

12. Bore two holes: one, straight through the 3cm dimension at 4cm(H); the second hole to be also about 3cm long, but from the center of the just bored hole through the 5cm dimension, but not straight through.
13. Insert a source through the first 3cm hole into the second 3cm hole of the polyurethane plug so that the end of the source with the silicone rubber plug just barely protrudes into the first 3cm hole of the polyurethane plug .
14. Prepare a small label (0.5cmx2.5cm) with the ID of the PMCH source and attach it securely to the polyurethane plug with a piece of clear tape all the way around.
15. Repeat the process until all sources are made. Place them in a box and store beneath another vented hood away from any potential contact of PMCH with CATs.

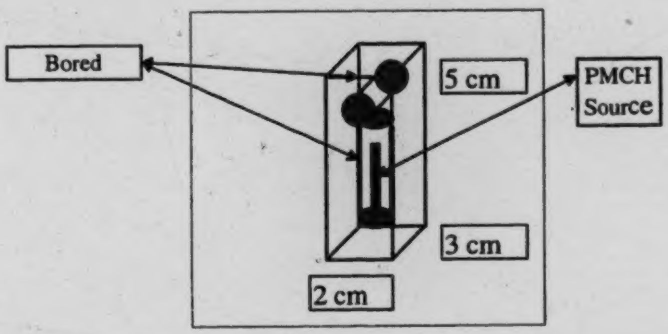


Figure 1. Polyurethane Holder and PMCH Source

B. Determination of permeation rate.

Apparatus, Materials, Supplies

PMCH permeation sources
Analytical balance with a readability/accuracy/precision of 0.1 mg.
Plastic tweezers
Worksheet template

Procedure

1. The PMCH source must be at least 3 weeks old prior to any weighing.
2. On the template, record the date, time, and temperature. Record the IDs of the PMCH sources.
3. Make sure the balance pan is clean (gently wipe with a fine artist brush) and rezero the balance.
4. Using the plastic tweezers, carefully extract the PMCH source from its polyurethane block holder and place on the balance pan.
5. Allow the reading to stabilize and record the weight. A new source weighs between 1.8 and 2.0 gm. whereas one at the end of its useful life is usually at or below 1.2 gm.
6. Remove the source from the balance pan and replace it in the polyurethane holder.
7. Check the zero and reset if necessary.
8. Weigh 9 more sources, then reweigh one of the previous nine by random selection.

9. Continue this procedure until all PMCH sources have been weighed and recorded.
10. If the weighing session is the first time the sources have been weighed, then stop here.
11. If this is the second or a subsequent weighing, then the permeation rate may be calculated. For a newer source at least 3 weighing sessions about 2 weeks apart each, are necessary for confirmation of a constant permeation rate. Sources should be weighed twice each, before and after field deployment.
12. The permeation rate is calculated by taking the difference in two weights from different weighing sessions, multiplying by 10^{-9} to convert grams to nanograms, and dividing by the time interval in minutes.

$$R_P = [(W_{Tf} - W_{Ti}) * 10^{-9} \ (\text{ng/gm})] / [\ (Tf - Ti) \times K] \qquad (1)$$

where

R_P = Permeation Rate in ng/ml
W_{Tf} = final weight of permeation source in gm.
W_T = initial weight of permeation source in gm
Tf = date and time of final weighing
Ti = date and time of initial weighing
K = factor for converting days to minutes (1440 minutes/day) and/or hours (60 minutes/hour)

13. General example/discussion: a total of 4 weighing sessions, 2 before and 2 after. Assuming the temperature to be 24 degrees C. for the interval between the first two sessions and the last 2 sessions, the permeation rate should reflect the same equilibrium conditions and be the same within experimental error. The permeation rate between the 2nd and 3rd weighing sessions represents the time interval during field deployment. Providing the temperature remained at 24 degrees C. and there was no mishandling of sources, the permeation rate should be the same as that measured in the lab. (Sources returned from the field should be weighed as soon as possible.) Any change in the permeation rate should obviously be consistent with field temperatures.

Permeation rate for the field at other than 24 degrees C. should also be calculated by applying the appropriate temperature correction factor to the lab measured rate, i.e. the rate obtained from the 1st/2nd and/or 3rd/4th session. The corrected rate should be close to the rate calculated for the 2nd/3rd session rate. When using the permeation rate for the AER calculation, select the rate which is most consistent with actual source history. For this one may consider that to reach a new permeation equilibrium at a different temperature, takes only a day or two compared to the 3 week duration needed for newly prepared sources. For homes where there is a diurnal variation in temperature, make the correction based on the average temperature determined by max-min thermometers.

4. Cleaning of CATs

The CAT sampling device consists of a short length of glass tubing (6.35 cm L x 0.6cm OD x 0.4cm ID) containing a small amount of a carbonized adsorbing material which is sandwiched in the middle by stainless steel screens. An identification number (ID) is permanently engraved on each sampler. The ends of the CAT are capped with either a polyurethane cap or a polyethylene cap. CATs are cleaned by thermally desorbing any adsorbed compounds from them at an elevated temperature in an inert nitrogen atmosphere.

Apparatus, Materials, Supplies:

23 position cleaning rack with attached nichrome heating coils
variable voltage transformer
low voltage, high current transformer
automatic programmable shut off timer (1500 watt)
ultrahighpurity nitrogen gas (tank with pressure regulator and needle valve)
standard lab tubing (rubber or polyethylene) to connect the gas tank/valves to the rack
flowmeter, 500 ml/min
carbon paper and/or activated charcoal tea bags
cleaning worksheet template
resealable plastic bag

Procedure:

1. On the worksheet, enter your name, date of cleaning, and IDs of CATs. Note any unusual CATs.
2. Remove the protective caps from 23 CATs and insert the CATS through the coils into the rack's retaining silicone O-rings. The rack is on the upper shelf of the cabinet below the fume hood. Make it protrude a few inches by sliding it toward the operator.
3. Turn on the nitrogen gas tank valve, adjust the pressure regulator to about 10 psi.
4. Attach a flowmeter to any of the 23 CATs and adjust the needle valve for a flow of about 15 ml/min.
5. Check the flow in the remaining 22 CATs to be in the range of 10-100 ml/min.
6. Remove the flowmeter.
7. With the variable voltage transformer set to zero, turn on the timer:
    A. Press the *T1*
    B. Press the *min* button until 25 has registered.
    C. Press *Outlet 1* to activate the outlet, red light on.
    D. Slowly turn the variable voltage transformer dial to a reading of 80. This should produce a just barely visible red-orange glow in the heating coils.
    E. Press *Start* on the timer.
8. After 25 minutes have elapsed, the timer automatically shuts off voltage to the variable voltage transformer. Allow about 15 more minutes for the heating coils to cool.
9. Replace the protective caps on 22 of the 23 CATs.
10. Turn off the nitrogen gas tank main valve, pressure regulator, and needle valve.
11. Remove the 23rd CAT with no cap and recap at both ends.
12. Remove the 22nd CAT and recap the one open end.
13. Proceed in similar fashion until all the CATs have been removed and recapped. Minimize the time spent doing this to reduce the amount of air that can diffuse into the CAT.

14. Place all the CATs in a plastic resealable bag containing protective carbon paper or 2 activated charcoal tea bags.
15. Label the bag: number of CATs, date cleaned, and initials. Store in a labeled drawer.
16. Place the worksheet in the Clean/QC file.
17. Allow the rack to cool down.
18. Replace the rack in its original position.

Safety: Perform this work in the fume hood area with no combustible solvents nearby. Attach a sign in a convenient location to indicate the high temperature hazard.

5. Quality Assurance

Apparatus, Materials, Supplies:

23 cleaned CATs
special gas chromatograph with autosampler and integrator (described below)
silicone grease
disposable latex gloves (non-powdered)

For most projects, all CATs are analyzed before being sent out to the field. For projects with many CATs (>500) each bag of 23 CATs is at least subsampled to check for contamination. The size of the subsample may vary but may never be less than 3 CATs (10%).

Upon QA analysis, CATs must have < 1.0 pl PMCH, or a peak at t_r~1.3 minutes with an area count < ~50000 counts. The actual area count must be determined by first establishing the value for 1.0 pl. This is easily done by determining the area count for a lab blank (=0.0 pl) and a standard PMCH in the range of 2.0 pl. If the CAT has < 5 pl PMCH (as measured from a recent standard curve) then it can be rerun. If the rerun is < 1.0 pl PMCH, then the CAT may be accepted, otherwise it must be recleaned by the usual process. All data and information must be recorded on the cleaning worksheet and the CAT QA worksheet.

Follow the same procedure for CAT analysis (described below).

Preparation of Standard CATs (for analysis)

Purpose and Design

A series of CATs are prepared with known amounts of PMCH (and optionally PDCH). Each analytical run of samples is accompanied by a full set of CAT standards covering the range of interest of PMCH. The standards are used to construct calibration curves for calculating the amount of PMCH in unknown samples.

A PMCH generator is used. It consists of a source of inert nitrogen gas flowing over a temperature-controlled PMCH source. Flow is measured by a soap-bubble flowmeter and temperature controlled by a constant temperature water bath. Aliquots of PMCH vapor in nitrogen are removed sequentially with a series of gas-tight syringes of increasing volumes through a T-septum arrangement downstream of the generator.

Apparatus, Materials, Supplies:

Ultrahigh purity nitrogen gas tank with regulator, 20 μm id glass capillary and holder, and connecting tubing.
Cleaned and QA'd CATs
Temperature controlled water bath and copper tubing
20 ml midget impinger
Chronometer or stopwatch
50 ml burette class A
glass T
tubing
soap bubble solution
gas-tight syringes: 10, 25, 50, 100, 250, and 500 μl.
charcoal paper or charcoal tea bags

Procedure:

1. Determine the nitrogen flowrate

Increase the regulator adjustment so that the secondary pressure is about 20 psi which corresponds to a flow of about 30 ml/min. Squeeze the bulb at the bottom of the glass tee to set in motion a soap bubble in the buret. When the bubble intersects the 50 ml line, start the chronometer; when the bubble intersects the 40 ml line, stop the chronometer. Record the elapsed time in seconds. Repeat two more times. Using the average of the 3 time readings calculate the nitrogen flow rate:

$$F\ (\text{ml/min}) = (10\ \text{ml} \times 60\ \text{sec/min})\ /\ \text{average time (sec)} \tag{2}$$

2. Reweigh the standard PMCH source in the midget impinger at least once per month and use equation (1) to calculate the standard PMCH source permeation weight, $r_{p\text{-}std}$ and record all data and information on the standard CAT worksheet.

3. Calculate the concentration of PMCH in the generator:

$$\text{PMCH}\ (\text{pl}/\mu\text{l}) = [r_{p\text{-}std}\ (\text{ng/min}) \times (24.45\ \text{nl}\ /350\ \text{ng}) \times 1000\ \text{pl/nl}]\ /\ [F\ (\text{ml/min}) \times 1000\ \mu\text{l/ml}\ ] \tag{3}$$

where (350 ng/24.45 nl) is a molecular weight-molecular volume conversion factor.
When $_{p\text{-}std}$ = 375 and F = 30, then PMCH (pl/μl) = 0.87 pl/μl.

4. Assemble from 1 to 9 sets of cleaned and QA'd CATs. Each set has 9 CATs. Every CAT must have an orange-brown silicone septum on the numbered end and on the plain end a black polyurethane cap or a red polyethylene Caplug, no. #EC-4. Record the CAT IDs on the Standard CATs worksheet.

5. Add the indicated μl of PMCH from the generator to the designated CATS using the syringe shown below:

amount of PMCH to be added:	syringe
0 µl	10 µl syringe
2 µl	10 µl syringe
4 µl	10 µl syringe
10 µl	25 µl syringe
20 µl	50 µl syringe
40 µl	100 µl syringe
100 µl	250 µl syringe
200 µl	500 µl syringe
0 µl	500 µl syringe

A. Check each syringe-needle for blockage by withdrawing the needle to about 80% of syringe volume, placing the needle tip in a beaker of water, and depressing the plunger. Look for air bubbles and remove the needle from the water while still depressing the plunger. Wipe the tip with lab tissue. If there is blockage, determine whether it's in the needle or the polytetrafluoroethylene (PTFE) needle retainer. Clean the former with the supplied wire. Clean the latter with the plunger. Be very careful not to deform, damage, or lose any parts. Use a low-power stereomicroscope if necessary.

B. For each of the "0" CATs pierce the CAT septum with the clean empty 10 µl syringe-needle, remove the needle and return the CAT to its storage position.

C. Repeat B. but with the clean empty 500 µl syringe-needle.

D. For the "2" to "20" CATs, insert the appropriate size syringe/needle into the metal T-septum on the PMCH generator and slowly "pump" the plunger at least 3 times. Set the plunger so that the PTFE tip end intersects the appropriate volumetric marking on the syringe. Withdraw the syringe from the generator septum.

E. Insert the syringe needle through the correspondingly appropriate standard CAT septum until the needle is within 5mm of the SS screen, and slowly depress the plunger all the way.

F. Remove the syringe needle and replace the CAT in its designated location.

G. Repeat D. through F. until all "2" to "20" standard CATs have been prepared.

H. For the "40" to "200" CATs, follow the same procedure as above except first withdraw air from the CAT before introducing the PMCH. This prevents pressure buildup and septum loosening. The amount of air to withdraw is twice the amount of standard PMCH to be introduced. E.g. withdraw 80 µl when preparing the 40 µl standard CAT.

I. Place some charcoal paper or charcoal tea bags in the standard CAT box , close, and store for at least 4 hours before using.

J. Make sure that all information has been recorded and store the worksheet in the file.

GC-ECD analysis of CATs

Introduction

The amount of PMCH adsorbed on CATs is determined by GC-ECD analysis. A very complete discussion of the GC (Varian Model 6000) and the technique can be found in Dietz, R. et al. This discussion is strictly limited to the operation of the system at HSPH.

Apparatus, Materials, Supplies:

Varian GC with ECD; GC heavily modified in semi-multi-dimensional configuration for analysis of PMCH.
Hewlett-Packard 3393A integrator
5% H_2 and 95% N_2 carrier gas
Strip chart recorders: 0-1 mv, 0-2 mv, 0-5 mv, and 0-10 mv.
Custom in-house built 23 sample-position autosampler
Chrontrol Lab Timer-Electrical Controller for 1 or 2 circuits.
Silicone grease
Q-tips
Lab supplies/expendables, e.g. tissues gloves, etc.
Analysis worksheets from templates.
Carrier gas is 5% H_2 and 95% N_2. House supplied air is regulated to 30 psi and provides the air pressure necessary for operation of the 4 6-port switching valves integrally located on the GC, and for maintaining a tight seal on the autosampler's 24-port switching valve (op cit).

A Hewlett-Packard 3393A integrator is attached to the integrator signal lead of the GC. The integrator parameters and Basic language have been used to automate data acquisition and preliminary data reduction.
Further signal acquisition is obtained on a strip chart using the GC recorder signal. Also the temperature of the special external Porapak GC column (op. cit.) is monitored by a thermocouple with the signal (0-2 mv)displayed on a stripchart recorder.

See the indicated Appendix below for the settings of all the instrumentation.

Appendix A.	Parameters for GC.
Appendix B.	Parameters for Integrator operational settings.
Appendix C	Program of Integrator data reduction.
Appendix D	Program for Timer which controls the recorder pens.
Appendix E	Recorders' settings.
Appendix F	Autosampler setting.

Procedure:
Autosampler

1. Enter CAT ID data on the GC Analysis worksheet; i.e. autosampler rack position, a number between 1 and 23, the corresponding CAT ID, and the type of CAT, standard (std) or field sample (unknown,). Every run must have all 9 standard CATs necessary to construct a standard curve. Also every one must have at least one(1) lab blank and/or field blank. A Run will have then either 12 or 13 unknown CATs .
2. Remove the cam adjusters and the top plate from the rack
3. Loosen the C-clamps on the bottom plate of the rack
4. Use gloves. Apply a small amount of silicone grease to a Q-tip (or equivalent). Carefully and lightly use the Q-tip to apply the grease to the red silicone O-rings in the bottom plate. Clear any visible excesses. The grease facilitates the insertion of the CATs into the O-rings. The 0-rings on the top plate must be greased only once every week .

5. Remove the cap from the plain unnumbered side of each CAT and insure that the top cap is not very tight
6. Insert the 23 CATs with the ID facing up, through the heating coils into the O-rings according to the sequence on the worksheet. Press firmly but do not force which can cause breakage. Adjust the C-clamps firmly but not too tightly
7. Replace the top plate carefully; line up the top of the CATs with the wells on the top plate and press it firmly down to seat barely the CATs.
8. Insert the cam adjusters holding the arm in the 3 o'clock position. Replace an finger-tighten the nuts on the cam-adjusting screw
9. Rotate the cam-adjusting arms counterclockwise slowly and carefully to set the CATs and seal the O-rings. Use care so as not to break anything.
10. Attach the bungee cord to the cam-adjusting arms to prevent the arms from loosening.
11. Check the autosampler's LED reading for position. If not (00) use the toggle switch on the respective controller to reset it to 0.00

GC Procedure

1. Check the A and B pressures on the right side of the instrument. The gauges should be pointing to the preset marks of 42 psi and 80 psi. The carrier gas pressure must be 80 psi as measured on the tank's regulator gauge
2. Insure that the integrator is in BASIC mode. Press "R" (for run) then "ENTER:. Follow the instruction on the integrator. When it prints "start pending" PROCEED.
3. Place the recorder ON/OFF toggle switch in the ON position. Activate the timer by pressing "CIRCUIT", "1", "ON", PROGRAM ", "1", "ON".
4. On the left side of the GC, press "SCHEDULE". Set the mode for "SINGLE PASS", if necessary. Repeatedly press "ENTER" to get to line 1 and enter "2" for the method # and "24" for the number of injections. Press the "ENTER: button, then "INSTRUMENT STATUS" A. Finally press "START" to initiate the run.
5. The run will go for about 3.5 hours. Check the progress frequently to make sure the instruments are functioning properly and the area counts for standards and blanks are in the proper range .
6. When the run has been completed, remove the strip chart and the integrator chart and place them in a labeled file folder along with the GC analysis worksheet.
7. Remove the CATs from the autosampler by reversing the procedure above.
8 . Recap the CATs and set them in the bin for cleaning.

Appendix A. Parameters for GC.

Oven temperature = 130 °C.
Oven temperature limit = 150 °C.
Run time = 8.5 minutes

Inj A temperature = 200 °C.
Inj B temperature = 200 °C.
Ion temperature (ECD) = 250 °C.
TCD temperature = OFF

Detector = 4 (ECD)
Range 10 (only two choices, 1 or 10)
Attenuation = 32 (0.1,1,2,4,8,16,32,64,128,256,512,1024)
AutoZero A ON
AutoZero B ON

Relay Settings:

Time	Relays ON	Relays OFF
0.01	3456	1278
0.25	12	
0.41		5
2.01	7	16
2.02		7
4.01	8	23
4.61	3	8

Appendix B. Parameters for Integrator operational settings.

Appendix C Program of Integrator data reduction.

Appendix D Program for Chrontrol Timer which controls the recorder pens.

To reset, the timer-controller should be disconnected from the wall outlet for at least one minute. Then perform the following key entry procedures:

TIME
ENTER
1
ENTER
CIRCUIT
1
OFF
INTERVAL
3
4
5
ENTER
ENTER
ENTER

TIME

To test the timer operation, first set up the program by pressing

TIME
ENTER
1
ENTER
CIRCUIT
1
ENTER
OFF
INTERVAL

after INTERVAL press

0
SEC
5
ENTER
TIME

to set the timer for a 5 second shutdown. To test, press

CIRCUIT
1
ON

and the circuit 1 indicator lamp should light.

Then press

PROGRAM
1
ON

at which time there should be a barely noticeable blink of the display; after 5 seconds, there should be an audible clicking sound simultaneous with the circuit 1 lamp light extinguishing. If this does not happen, then try reentering the program. When the test is successful, repeat the key entry procedure above entering 345 instead of the SEC 5 after the INTERVAL.

Calculations

Standard Curve

There is a spreadsheet template for entering the area counts from the integrator. It is straightforward and produces the calculated data for the unknowns. The replacement equations used in the template are very complex and it is suggested not to alter them. They are designed to produce a point-to-point fit for the standard curve. The curve's shape tends toward a quadratic as long as the amount of PMCH does not exceed about 400 picoliters. Note that the PMCH standard curve is not linear and so linear regression analysis (least squares analysis) cannot be used successfully across the entire range of interest.

Short of the template, one can devise their own spreadsheet as follows. Let the pl of PMCH from the standard CATs be the Y values and the area counts from the integrator be the X values. Enter these values in a spreadsheet which can perform either a quadratic fit or a point-to-point linear fit (sometimes termed a piecewise fit). Cubic may also work. The spreadsheet should be able to draw the standard curve and calculate the values of X for given values of Y.

Preparation of Standard Curve

From the PMCH source permeation rate and the measured nitrogen flow from the PMCH generator, calculate the PMCH concentration(pl/μl) of the standards used as described earlier. Enter this value into the designated cell in the spreadsheet. Enter the corresponding area counts into the designated cell(s) in the spreadsheet.

[Alternatively, multiply the PMCH concentration by the percent of PMCH in the reagent (usually 90%). Multiply this by the volume(μl) of gas used for each standard to get the total amount of PMCH.]

Calculation of PMCH in Unknowns

For the complete run, enter the sample (standard) ID and the corresponding integrator area counts into designated cells in the spreadsheet. **SHOW AN EXAMPLE** Now, the final data appears in the adjoining cells and the standard curve can be seen in the nearby chart

The concentration of PMCH in unknowns is calculated from the unknown area counts, the amount of PMCH in the standard with next least area counts, and the slope for the corresponding area count point on the standard. The slope is obtained either from the point-to-point fit or the quadratic equation. **IS THIS CLEAR OR CONFUSING?**

Organization of Files and Worksheets **SHOW EXAMPLES**

Worksheets
Source Permeation Rates
Cleaned CATs
QA'd CATs
Standard CATs

Files

GC Analyses
Sources
CATs
Clean
QA'd

Computer

Sources

Templates
Clean and Run
Standards
Special Runs
Data and Results

Shipping Procedures

Sources

Sources and CATs should never be transported together nor on the same day. Sources should be shipped in resealable plastic bags in a box within a box. Their value is usually listed at $0.50 to $1.00 each. Paper records should be maintained showing what carrier, when, and the airbill or waybill number.

CATs

CATs are in resealable plastic bags with charcoal protection. These bags must be placed with charcoal paper or equivalent in a box within box for shipping. The declared value is $1.00 each.

Boxes for shipping should be adequately cushioned and taped with 3" postal tape or equivalent.

Field Sampling

Introduction

As with any chemical determination, the data are only as good as the sample. PFT AER is a passive technique operating in a possibly heterogeneous sampling theater. So, attention to numbers of sources and CATs as well as careful placement of PMCH sources and CATs are very probably the most important parts of the AER protocol.

Determination of the Number of Sources

The number of sources is determined by rearrangement of Equation

$AER = (N * R_{Perm} * R_{CAT} * T_{CAT})/(V_{PMCH} * V_{house})$
and obtaining:
$N = [AER * (V_{PMCH} * V_{house})] / (R_{Perm} * R_{CAT} * T_{CAT})$
where
N = number of PFT sources used
R_{Perm} = PFT permeation rate in ng/min
R_{CAT} = CAT collection rate in liters/hr = 0.00838
T_{CAT} = CAT exposure time in min
V_{PMCH} = picoliters of PMCH found on CAT (GC analysis)
V_{house} = house volume in cubic feet
and conversion factors:
60 min/hr
28.3 lit/cubic foot
1,000,000,000 ng /gm
1000 picoliters/nanoliter

PMCH molecular weight = 350 gm/mole or ng/nmole
PMCH molecular volume = 24.45 lit/mole or nl/nmole

A desirable amount of PMCH to collect on a CAT is in the range of 20-100 µl. The sampling time is determined according to convenience, subjective assessment, and consideration of other simultaneous sampling.

To calculate the number of sources needed in a given location, using an estimate of 0.2 air changes per hour and an average $R_{Perm} = 300$ ng/min and a house volume of 6,048 cubic feet, with an exposure of 24 hours, then to collect 25 pl PMCH,

$N = [AER \bullet (V_{PMCH} \bullet V_{house})] / (R_{Perm} \bullet R_{CAT} \bullet T_{CAT})$ or

$N = [0.2 \text{ air changes per hour} \bullet (25 \text{ pl} \bullet 6048 \text{ cubic feet} \bullet (28.3 \text{ lit/cubic foot})] / (300 \text{ ng/min} \bullet \{24.5 \text{ nl}/350 \text{ ng}\} \bullet (1000 \text{ pl/nl}) \bullet 0.008308 \text{ lit/hr} \bullet 24 \text{ hr} \bullet 60 \text{ min/hr})$

$N = 2$ sources.

Determination of the Number of CATs

The number of CATs to be employed is determined according to the type of information desired. For average air exchange rate, as few as 1 or 2 CATs can be used if optimally placed. For a more accurate measure of average air exchange rate, CATs may be located in every room in the house or building. If one wants to know the AER for a given room, then 2 or more CATs may be placed there as well as a PMCH source. This can get very complex very quickly when one considers that air exchange occurs not only with the outdoors through window areas, but also within the home through the door. In this case it is best to employ another tracer, say PDCH, in a nearby hallway to determine the rate of inflow of air into the target room from the hallway, i.e. some measure of the air exchange between hallway and target room. This should be complemented by placing CATs in the hallway to measure the PMCH and thus get an independent measure of outflow of air into the hallway. Some of these issues are discussed in detail in references 1 and 2.

In addition to the above, there should be at least 10% duplicate CATs and 10% Field Blanks.

Locating Sources and CATs

As can be seen from the immediately preceding paragraph, the optimal positioning of sources and CATs is necessary to obtain the most meaningful AER data. A complete discussion is beyond the scope of this document.

Some general considerations can be stated however. Sources and CATs should be placed in areas which allow relatively free but not forced movement of air. CATs should be as close as reasonably possible to the breathing height for both sitting and standing and be in an area which is representative of where occupants sit or stand, and representative of the AER in that room. This is obviously a very subjective judgement in the absence of additional instrumentation. Sources should be in an area that allows the tracer to disperse evenly and be transported in the dwelling to all locations which influence the AER.

Among the areas to avoid are windows and doors where there are strong drafts or winds, stairways which have increased vertical air movement due to thermal effects, adjacent to walls or or in "cubbyholes", and away from sources of heat or cold, and appliances such as refrigerators and dehumidifiers which contain Freons, a potential interferent in the analysis.

It is good for CATs to be suspended if possible, or placed on a flat surface with the exposed end protruding beyond the end of the surface, e.g. a table or mantle or bookcase or bureau.

Deploying Sources and CATs

The sources are contained in polyurethane blocks and should never be touched or removed. There is one source per block. Sources are sent to the field in resealable plastic bags. They are never shipped or transported together anywhere with CATs particularly regarding the sampling location. Sometimes some charcoal is placed with the sources. The charcoal absorbs the PMCH so that it cannot escape or contaminate anything. Every block has an external ID which matches the source contained within. Sources can be secured by taping (removable type adhesive tape) or tying with a string (using the available hole in the block). Dental floss is a very convenient material for the latter. Orientation, though not the most important issue, should still be considered: try to secure so the ID is in readable position. Record the date, time, and location (include a sketch) on the sample data sheet.

The CAT samplers are packaged 5 to a resealable plastic bag; they should always be protected by charcoal, paper, tea bag, or equivalent. CATs are set out 24 hours or longer after the sources have been deployed. They can be taped (removable type adhesive tape) or secured with a wire or plastic tie, or tied with dental floss. They should never be closer than six (6) feet from a PMCH source. Once the location is selected and the CAT secured, the sampling CAT is "activated" by removing the cap on the numbered end and positioning it by having the open end facing down, to minimize collection of particles. Record the date, time, and location of the CAT on the sample data sheet.

Field Blanks

Field Blanks (CATs) are transported to the sampling location, and treated identically to unknowns except they are opened then immediately closed. They should be protected by charcoal paper or tea bags, replaced in the plastic bag, and left at the house if convenient, otherwise taken to the local field office or equivalent where there is no source of unprotected PMCH.

Duplicates

Duplicate CATs are used to establish precision. They are prepared and treated identically to the main CAT. They should be placed next to the main CAT within about 3-6 inches. Both duplicates and Field Blanks should be recorded on the sample data sheet.

8.4 Appendix D

Equations for the calculation of flowmeter set point and PM air concentration calculations.

Calculations are based on equations recommended by Airmetrics (AirMetrics, 1998).

Flowmeter set point calculation

$$k_{amb} = \sqrt{\left(\frac{P_{cal}}{P_{amb}}\right)\left(\frac{T_{amb}}{T_{cal}}\right)}$$

With
k_{amb} = Flowmeter correction factor
P_{amb} = Ambient atmospheric pressure [kPa]
T_{amb} = Ambient air temperature [K]
P_{cal} = Atmospheric pressure during sampler calibration [kPa]
T_{cal} = Air temperature during calibration [K]

$$Q_{std} = 5.0\left(\frac{P_{amb}}{P_{std}}\right)\left(\frac{T_{std}}{T_{amb}}\right)$$

with:
Q_{std} = Flowrate at standard conditions [l/min]
T_{std} = Standard Temperature (298 K)
P_{std} = Standard Pressure (101.325 kPa)

$$I_{sp} = \frac{k_{amb}\left(Q_{std} - b_{std}\right)}{m_{std}}$$

I_{sp} = Indicated flowrate
b_{std} = Intercept (from MiniVol calibration curve)
m_{std} = Slope (from MiniVol calibration curve)

Calculation of PM Air Concentration

$$V_{std} = \frac{Q_{std} * t_h * 60_{\min/h}}{1000_{l/m^3}}$$

with

V_{std} = Volume of air passing through filter at standard conditions [m^3]
t_h = sampling period [h]

$$V_{amb} = V_{std} * \left(\frac{P_{std}}{P_{amb}}\right)\left(\frac{T_{amb}}{T_{std}}\right)$$

with

V_{amb} = Volume of air passing through the filter at ambient conditions

$$PM_{amb} = \frac{M_{PM}}{V_{amb}}$$

with

PM_{amb} = PM concentration [$\mu g/m^3$]
M_{PM} = Mass of particulate matter collected on filter [μg].

Assumptions:

T_{amb} and P_{amb} obtained from Environment Canada, Ft .McMurray airport station approximately 1 hour before sampler deployment
Below detection limit data substituted with one half method detection limit (1.5 $\mu g/m^3$)
Sampling period as recorded on field log book

8.5 Appendix E

Field Data

8.5.1 Fall 1999 PM_{10} Time Weighted Average Concentrations

Fall 1999			
		INDOOR	AMBIENT
Location	Date	PM_{10} [µg/m^3]	PM_{10} [µg/m^3]
10	23-Sep	64.3	4.9
19	25-Sep	6.2	2.9
6	26-Sep	39.6	7.9
2	27-Sep	61.0	10.2
14	27-Sep	123.0	10.2
12	28-Sep	145.0	15.6
21	29-Sep	n/a	3
18	29-Sep	77.2	3
11	30-Sep	23.4	7.5
8	1-Oct	125.3	n/a
23	1-Oct	7.1	n/a
3	2-Oct	164.1	5.3
5	2-Oct	24.4	5.3
17	3-Oct	27.5	3.1
20	3-Oct	51.5	3.1
7	4-Oct	38.3	2.3
13	12-Oct	144.2	20.5
26	12-Oct	39.3	20.5
4	13-Oct	89.2	2
25	14-Oct	138.5	1.8
31	14-Oct	31.3	1.8
22	15-Oct	53.2	2.5
30	15-Oct	85.9	2.5
9	16-Oct	76.9	3.3
15	16-Oct	99.4	3.3
1	17-Oct	78.6	4.7
24	17-Oct	30.5	4.7
29	17-Oct	212.1	4.7
16	18-Oct	164.8	7.6
28	18-Oct	98.4	7.6
27	19-Oct	150.5	4.7

8.5.2 *Winter PM_{10} Time Weighted Average Concentrations*

Winter 2000				
		Indoor	**Ambient**	**Outdoor**
Location	Date	PM_{10} [$\mu g/m^3$]	PM_{10} [$\mu g/m^3$]	PM_{10} [$\mu g/m^3$]
18	19-Jan	38.3	n/a	n/a
30	19-Jan	43.9	n/a	n/a
23	20-Jan	5.9	14.2	18.8
25	20-Jan	142.4	14.2	18.8
12	21-Jan	62.0	4.1	15.7
16	21-Jan	110.6	4.1	15.7
4	22-Jan	3.4	6.9	8.1
28	22-Jan	56.1	6.9	8.1
20	23-Jan	42.5	n/a	n/a
21	23-Jan	21.4	n/a	n/a
6	24-Jan	20.1	n/a	17.4
7	24-Jan	50.0	n/a	17.4
1	25-Jan	105.3	25	27.5
2	25-Jan	71.7	25	27.5
11	26-Jan	60.1	17.9	19
31	26-Jan	31.8	17.9	19
24	27-Jan	19.3	12.5	13.1
26	27-Jan	40.8	12.5	13.1
8	28-Jan	35.5	7.4	12.6
9	28-Jan	113.8	7.4	12.6
19	28-Jan	10.7	7.4	11.2
17	29-Jan	35.8	5.7	6.7
15	29-Jan	7.9	5.7	6.7
5	30-Jan	30.7	n/a	16.5
29	30-Jan	50.0	n/a	16.5
13	31-Jan	51.4	29.1	26.3
10	31-Jan	41.2	29.1	26.3
3	1-Feb	n/a	27.9	26.3
27	1-Feb	116.4	27.9	26.8
14	2-Feb	26.2	23.7	22.8

8.5.3 PM_{10} Replicates

INDOOR	X1	X2	X1-X2	RSD [%]
1	33.2	29.5	3.7	8.3
2	152.8	148.1	4.7	2.2
3	29.2	26.8	2.4	6.1
4	7.1	4.7	2.4	28.8
5	63.4	60.7	2.7	3.1
6	59.7	52.5	7.2	9.1
7	43.3	41.7	1.6	2.7
8	62.6	57.5	5.1	6.0
9	9.4	6.4	3	26.8
10	116.7	116.1	0.6	0.4
AMBIENT/OUTDOOR	**X1**	**X2**	**X1-X2**	**RSD**
1	9.1	6.1	3.0	27.9
2	25.1	24.9	0.1	0.4
3	17.9	16.3	1.6	6.7
4	15.9	15.4	0.5	2.2
5	18.9	15.9	3.0	12.2
6	17.9	15.1	2.8	11.8
7	23.1	22.5	0.6	1.9

8.5.4 Air Exchange Data

Fall 1999		
Location	**Date**	**ACH**
10	23-Sep	0.23
19	25-Sep	0.57
6	26-Sep	0.46
2	27-Sep	n/a
14	27-Sep	n/a
12	28-Sep	0.69
21	29-Sep	0.03
18	29-Sep	0.50
11	30-Sep	0.47
8	1-Oct	0.52
23	1-Oct	0.01
3	2-Oct	0.21
5	2-Oct	0.15
17	3-Oct	0.44
20	3-Oct	0.22
7	4-Oct	0.18
13	12-Oct	0.21
26	12-Oct	0.29
4	13-Oct	0.27
25	14-Oct	0.35
31	14-Oct	0.41
22	15-Oct	0.29
30	15-Oct	0.39
9	16-Oct	0.52
15	16-Oct	0.19
1	17-Oct	n/a
24	17-Oct	0.63
29	17-Oct	n/a
16	18-Oct	0.15
28	18-Oct	0.37
27	19-Oct	n/a

8.5.5 *Meteorological Data*

Data averaged from 16:00 h to 15:59 h the following day

Fall 1999

DATE	TEMPERATURE [°C]	R.H. [%]	WIND SPEED [km/h]
23-Sep-99	12.0	50	10
25-Sep-99	7.5	55	10
26-Sep-99	4.9	70	7
27-Sep-99	2.6	68	12
27-Sep-99	2.6	68	12
28-Sep-99	5.3	57	13
29-Sep-99	-1.1	53	9
29-Sep-99	-1.1	53	9
30-Sep-99	-2.7	64	5
1-Oct-99	-2.2	62	8
1-Oct-99	-2.2	62	8
2-Oct-99	0.1	68	6
2-Oct-99	0.1	68	6
3-Oct-99	-0.3	75	5
3-Oct-99	-0.3	75	5
4-Oct-99	-0.1	87	6
12-Oct-99	3.2	66	10
12-Oct-99	3.2	66	10
13-Oct-99	4.5	82	8
14-Oct-99	1.3	90	7
14-Oct-99	1.3	90	7
15-Oct-99	0.1	89	10
15-Oct-99	0.1	89	10
16-Oct-99	2.1	86	9
16-Oct-99	2.1	86	9
17-Oct-99	-0.2	82	8
17-Oct-99	-0.2	82	8
17-Oct-99	-0.2	82	8
18-Oct-99	6.5	68	10
18-Oct-99	6.5	68	10
19-Oct-99	11.5	54	11

Winter 2000

DATE	TEMPERATURE [°C]	r.H. [%]	WIND SPEED [km/h]
20-Jan-00	-20.8	81	7
21-Jan-00	-18.9	82	5
22-Jan-00	-11.6	84	10
24-Jan-00	-11.4	82	9
25-Jan-00	-14.8	84	8
26-Jan-00	-12.7	84	8
27-Jan-00	-4	75	12
28-Jan-00	-5	85	6
28-Jan-00	-5	85	6
29-Jan-00	-2	63	8
30-Jan-00	-10.2	79	3
31-Jan-00	-8.3	78	8
1-Feb-00	-6.4	65	3
1-Feb-00	-6.4	65	3
2-Feb-00	-11	65	6

8.5.6 $PM_{2.5}$ Data

Data averaged from 16:00 h to 15:59 h the following day

FALL 1999	$PM_{2.5}$	WINTER 2000	$PM_{2.5}$
22-Sep-99	5.3	19-Jan-00	11.8
23-Sep-99	2.6	20-Jan-00	8.7
24-Sep-99	3.3	21-Jan-00	5.9
25-Sep-99	3.3	22-Jan-00	4.5
26-Sep-99	3.6	23-Jan-00	4.6
27-Sep-99	3.6	24-Jan-00	8.4
28-Sep-99	4.7	25-Jan-00	11.0
29-Sep-99	2.7	26-Jan-00	9.1
30-Sep-99	3.0	27-Jan-00	6.7
1-Oct-99	2.3	28-Jan-00	4.5
2-Oct-99	3.8	29-Jan-00	4.9
3-Oct-99	3.7	30-Jan-00	7.6
4-Oct-99	3.1	31-Jan-00	9.5
5-Oct-99	5.1	1-Feb-00	11.6
6-Oct-99	9.7	2-Feb-00	11.0
7-Oct-99	4.1		
8-Oct-99	4.4		
9-Oct-99	5.6		
10-Oct-99	5.6		
11-Oct-99	7.7		
12-Oct-99	6.9		
13-Oct-99	2.5		
14-Oct-99	3.2		
15-Oct-99	3.5		
16-Oct-99	4.7		
17-Oct-99	4.2		
18-Oct-99	4.9		
19-Oct-99	3.8		
20-Oct-99	3.1		
21-Oct-99	3.7		
22-Oct-99	7.5		

8.5.7 Results of Statistical Analysis

The following tables list the summaries for the statistical tests performed.

Difference in air exchange for houses and trailers

t-Test: Two-Sample Assuming Equal Variances		
	AEX house	***AEX trailer***
Mean	0.35	0.32
Variance	0.03	0.04
Observations	17	9
Hypothesized Mean Difference	0	
df	24	
t Stat	0.4	
P(T<=t) two-tail	0.740	
t Critical two-tail	2.4	
alpha = 0.025		
t stat < t critical => fail to reject Ho		

Difference in means between fall indoor and ambient PM_{10} concentrations

t-Test: Paired Two Sample for Means		
	indoor fall	***ambient fall***
Mean	84	6
Variance	2863	26
Observations	28	28
Pearson Correlation	0.19	
Hypothesized Mean Difference	0	
df	27	
t Stat	7.8	
P(T<=t) two-tail	2.4E-08	
t Critical two-tail	2.1	
alpha = 0.025		
t Stat > t critical => reject Ho		

Difference in means between winter indoor and ambient PM_{10} concentrations

t-Test: Paired Two Sample for Means

	indoor winter	*amb-out winter*
Mean	52	15
Variance	1479	67
Observations	25	25
Pearson Correlation	0.16	
Hypothesized Mean Difference	0	
df	24	
t Stat	4.9	
P(T<=t) two-tail	5.6E-05	
t Critical two-tail	2.1	
alpha = 0.025 t stat > tcrit => reject Ho		

Seasonal difference in ambient PM_{10} concentrations

t-Test: Two-Sample Assuming Equal Variances

	ambient fall	*ambient winter*
Mean	6	15
Variance	26	83
Observations	29	22
Hypothesized Mean Difference	0	
df	49	
t Stat	-4.5	
P(T<=t) two-tail	4.2E-05	
t Critical two-tail	2.0	
alpha = 0.025		
t stat <negative t critical => reject Ho		

Seasonal difference in indoor PM_{10} concentrations

t-Test: Paired Two Sample for Means		
	indoor fall	***indoor winter***
Mean	80	51
Variance	2860	1326
Observations	28	28
Pearson Correlation	0.5	
Hypothesized Mean Difference	0	
df	27	
t Stat	3.2	
P(T<=t) two-tail	3.4E-03	
t Critical two-tail	2.1	
alpha = 0.025		
t Stat > tcritical => reject Ho		

Difference between fall and winter $PM_{2.5}$ concentrations

t-Test: Two-Sample Assuming Equal Variances		
	Fall $PM_{2.5}$	**Winter $PM_{2.5}$**
Mean	4	8
Variance	3	7
Observations	31	15
Hypothesized Mean Difference	0	
df	44	
t Stat	-5.6	
P(T<=t) two-tail	1.46E-06	
t Critical two-tail	2.0	
alpha = 0.025		
tstat < negative tcritical => reject Ho		